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Seo et al.

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(54) **LIGHT-EMITTING ELEMENT, DISPLAY DEVICE, ELECTRONIC DEVICE, AND LIGHTING DEVICE**

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(72) Inventors: **Satoshi Seo**, Kanagawa (JP); **Takao Hamada**, Toyama (JP)

(73) Assignee: **Semiconductor Energy Laboratory Co., Ltd.**

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(51) **Int. Cl.**

H01L 51/00 (2006.01)

G06F 3/041 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC **C07F 15/0033** (2013.01); **C09K 11/06** (2013.01); **G06F 3/045** (2013.01);

(Continued)

(58) **Field of Classification Search**

None

See application file for complete search history.

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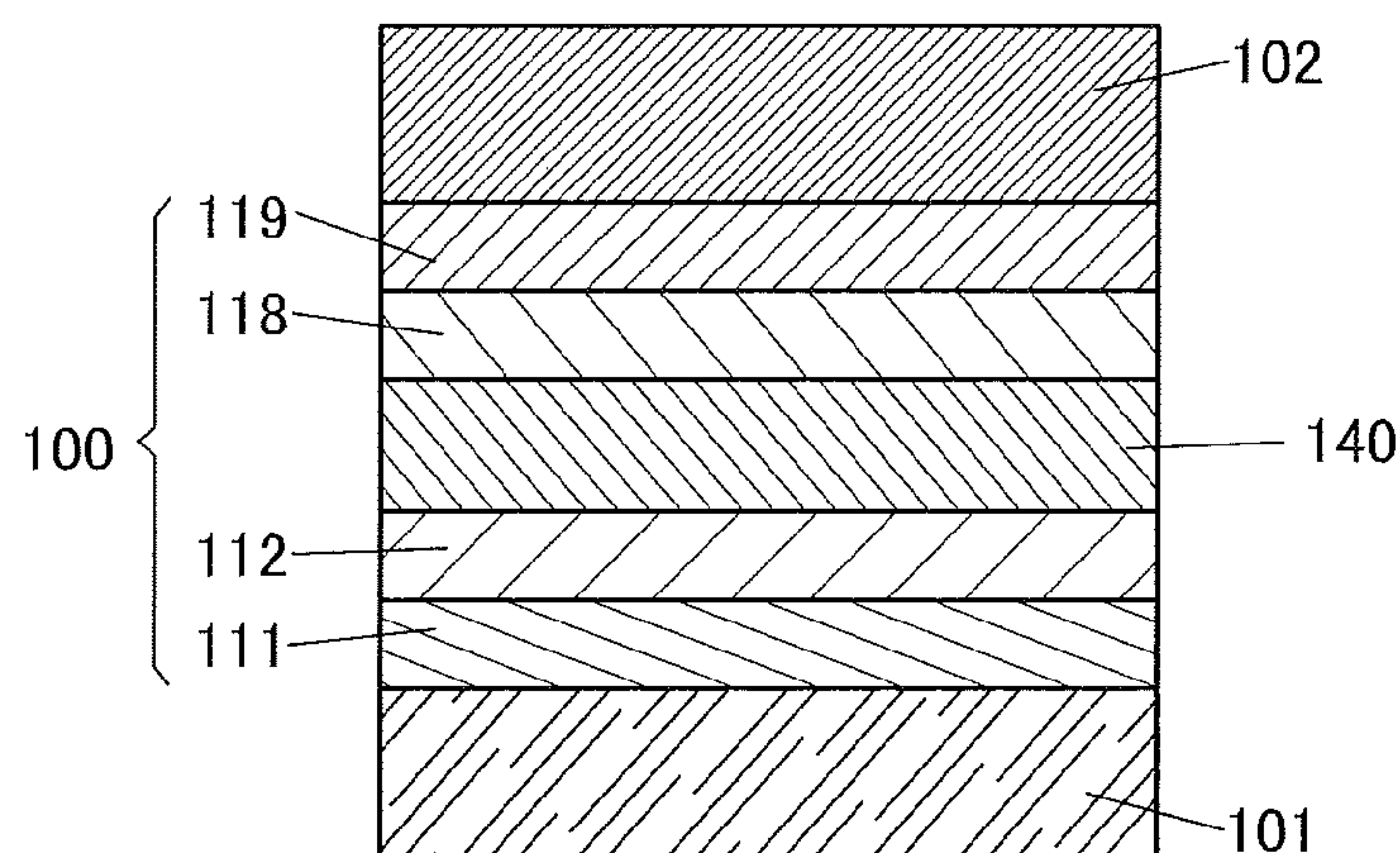
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ABSTRACT

Provided is a light-emitting element including a first organic compound, a second organic compound, and a guest material. The LUMO level of the first organic compound is lower than that of the second organic compound. The HOMO level of the first organic compound is lower than that of the second organic compound. The LUMO level of the guest material is higher than that of the first organic compound. The HOMO level of the guest material is higher than that of the second organic compound. An energy difference between the LUMO level and the HOMO level of the guest material is larger than an energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound. The guest material can convert triplet excitation energy into light emission. The combination of first organic compound and the second organic compound can form an exciplex.

40 Claims, 70 Drawing Sheets

152
↘



- (51) **Int. Cl.**
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C07F 15/00 (2006.01)
H01L 51/50 (2006.01)
H05B 33/14 (2006.01)
H05B 33/20 (2006.01)
- (52) **U.S. Cl.**
 CPC **G06F 3/0412** (2013.01); **H01L 51/0051** (2013.01); **H01L 51/0085** (2013.01); **H01L 51/5004** (2013.01); **H01L 51/5016** (2013.01); **H05B 33/14** (2013.01); **H05B 33/20** (2013.01); **C09K 2211/1007** (2013.01); **C09K 2211/1044** (2013.01); **C09K 2211/1059** (2013.01); **C09K 2211/185** (2013.01); **G06F 3/0443** (2019.05); **G06F 3/0446** (2019.05); **G06F 2203/04102** (2013.01); **G06F 2203/04111** (2013.01); **H01L 51/006** (2013.01); **H01L 51/0052** (2013.01); **H01L 51/0061** (2013.01); **H01L 51/0067** (2013.01); **H01L 51/0071** (2013.01); **H01L 51/0072** (2013.01); **H01L 51/0074** (2013.01); **H01L 51/5028** (2013.01); **H01L 51/5056** (2013.01); **H01L 51/5072** (2013.01); **H01L 2251/5384** (2013.01); **H01L 2251/552** (2013.01)
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FIG. 1A

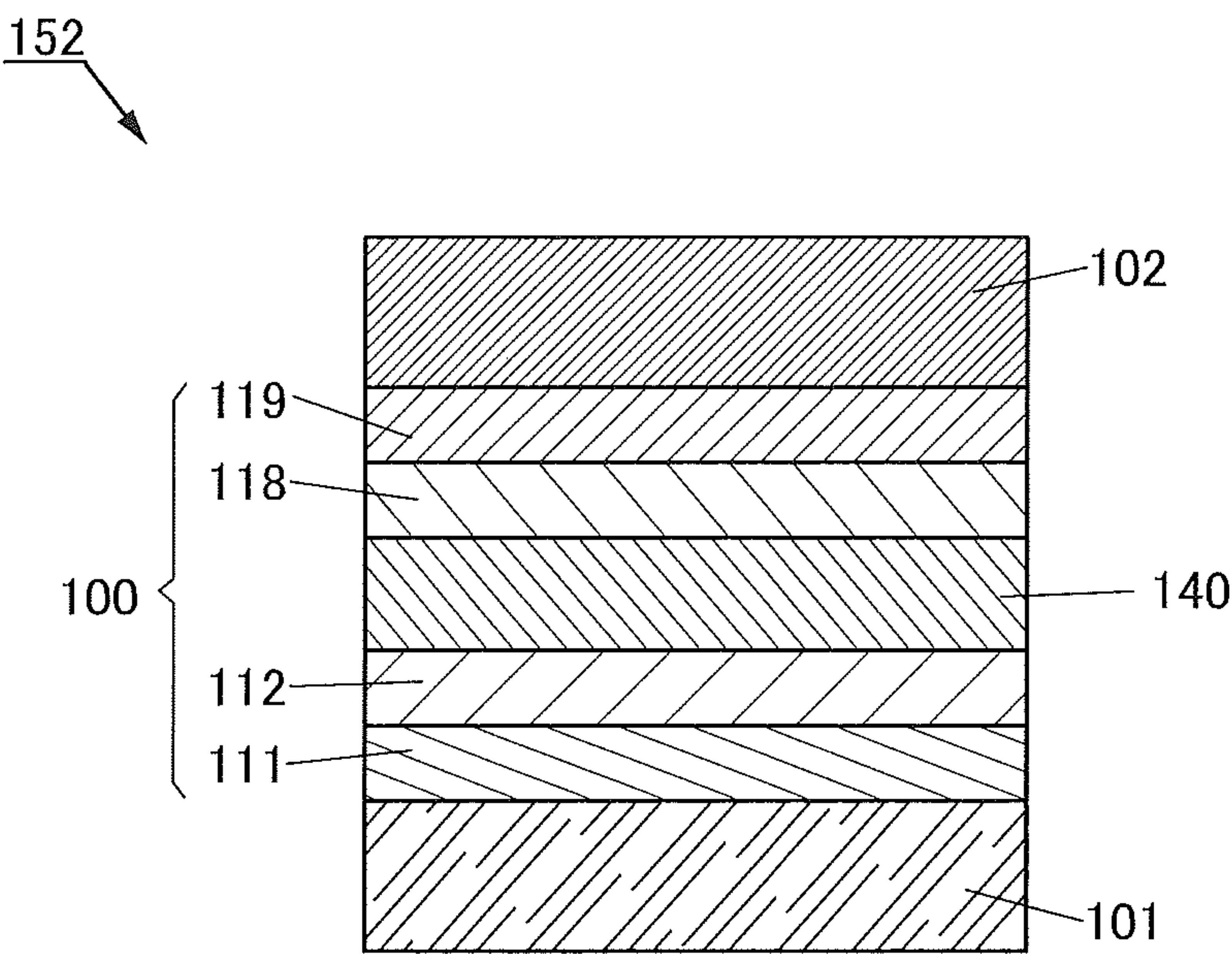


FIG. 1B

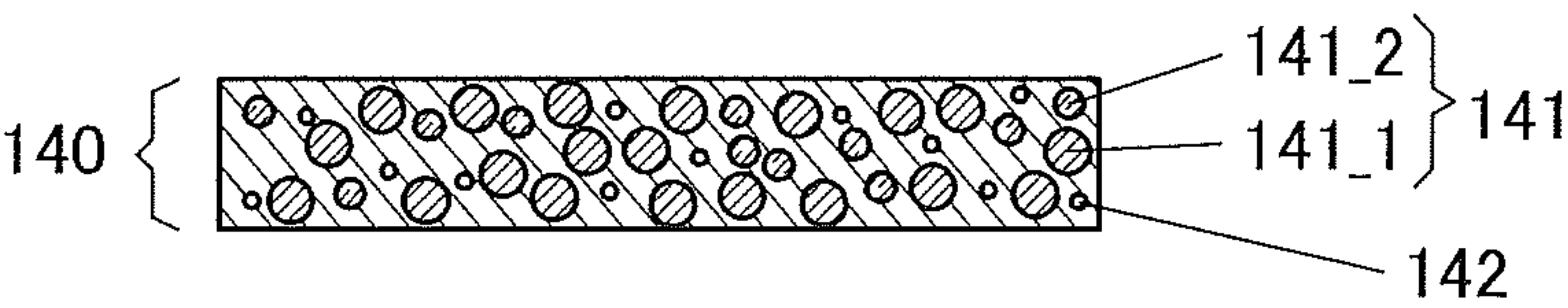


FIG. 2A

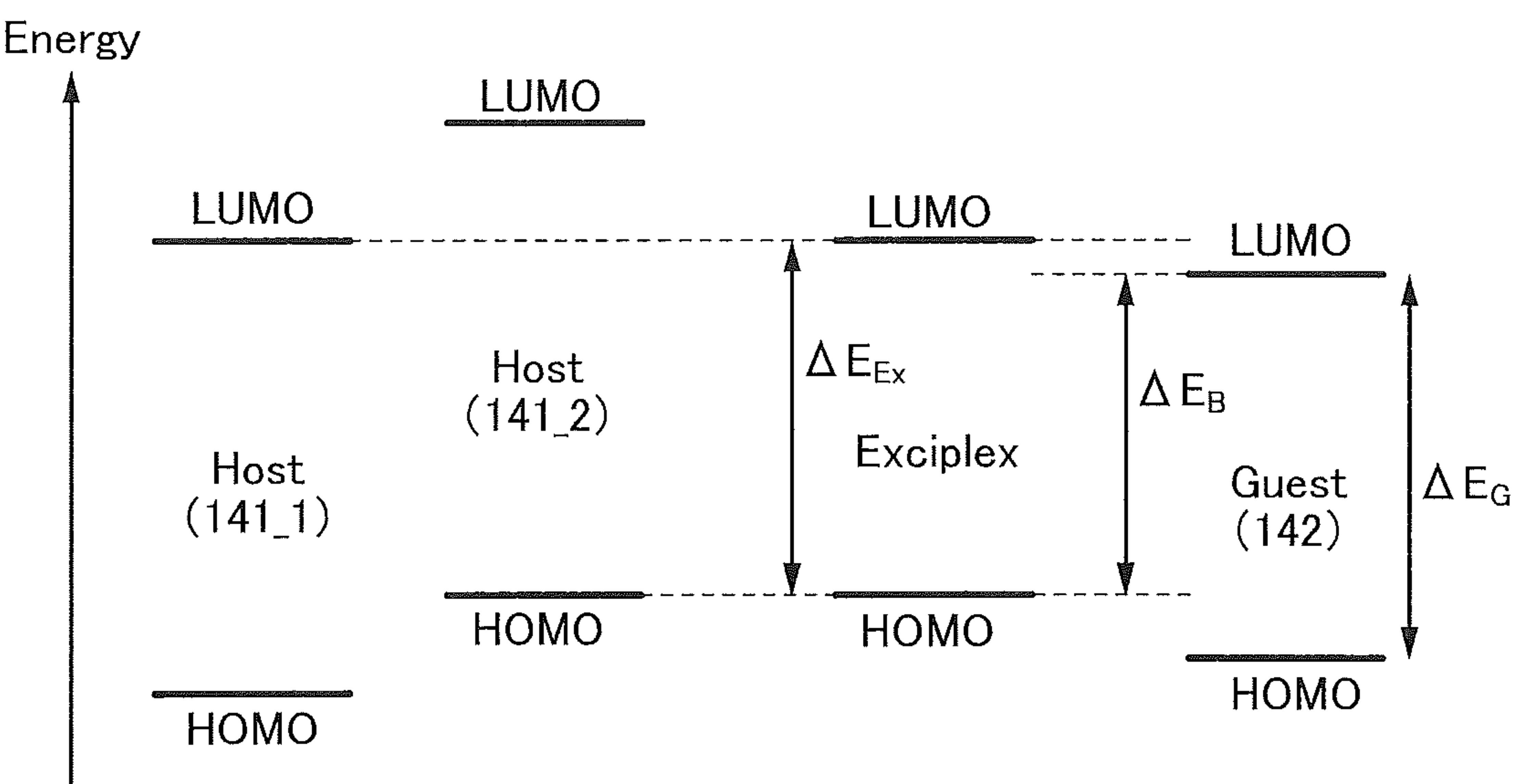


FIG. 2B

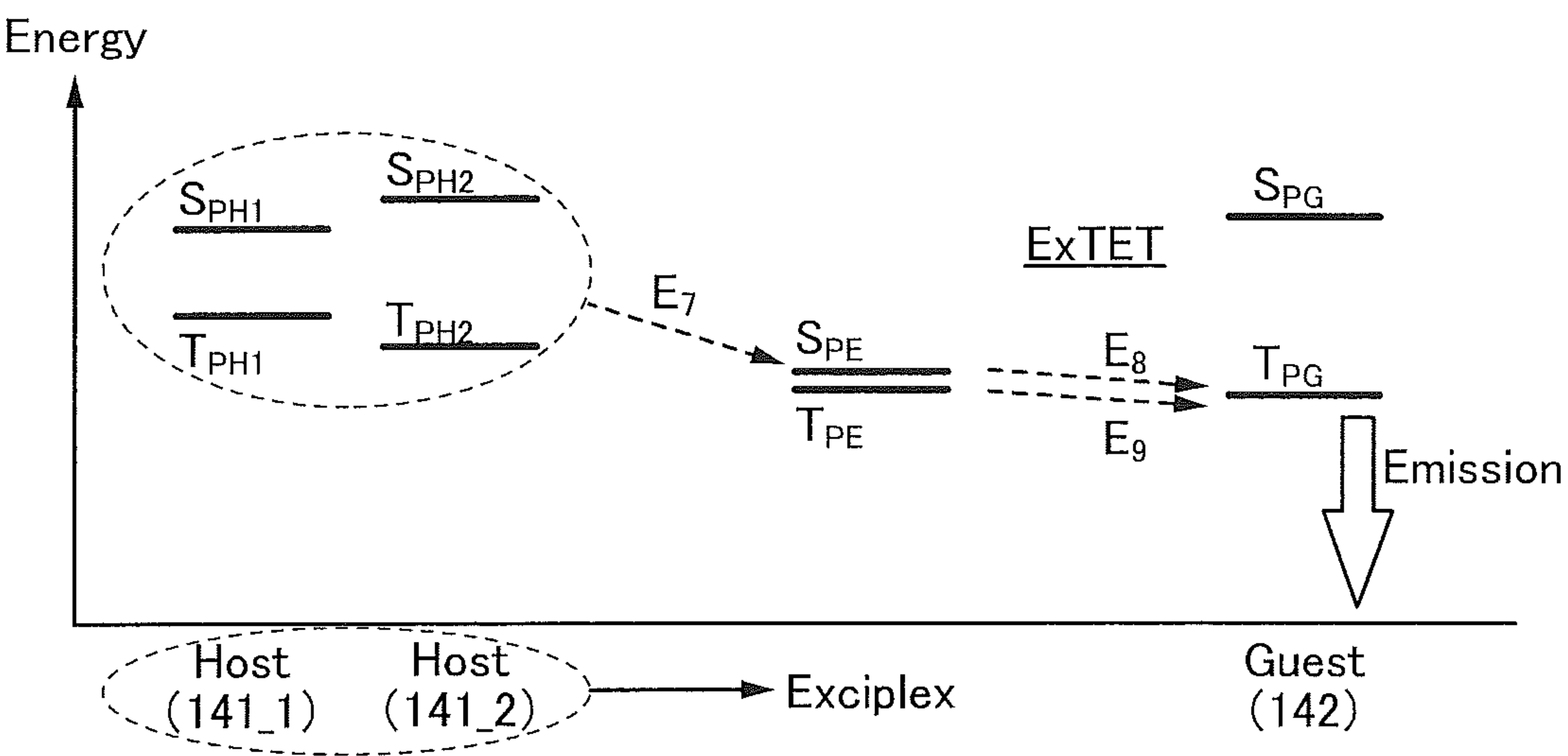


FIG. 3A

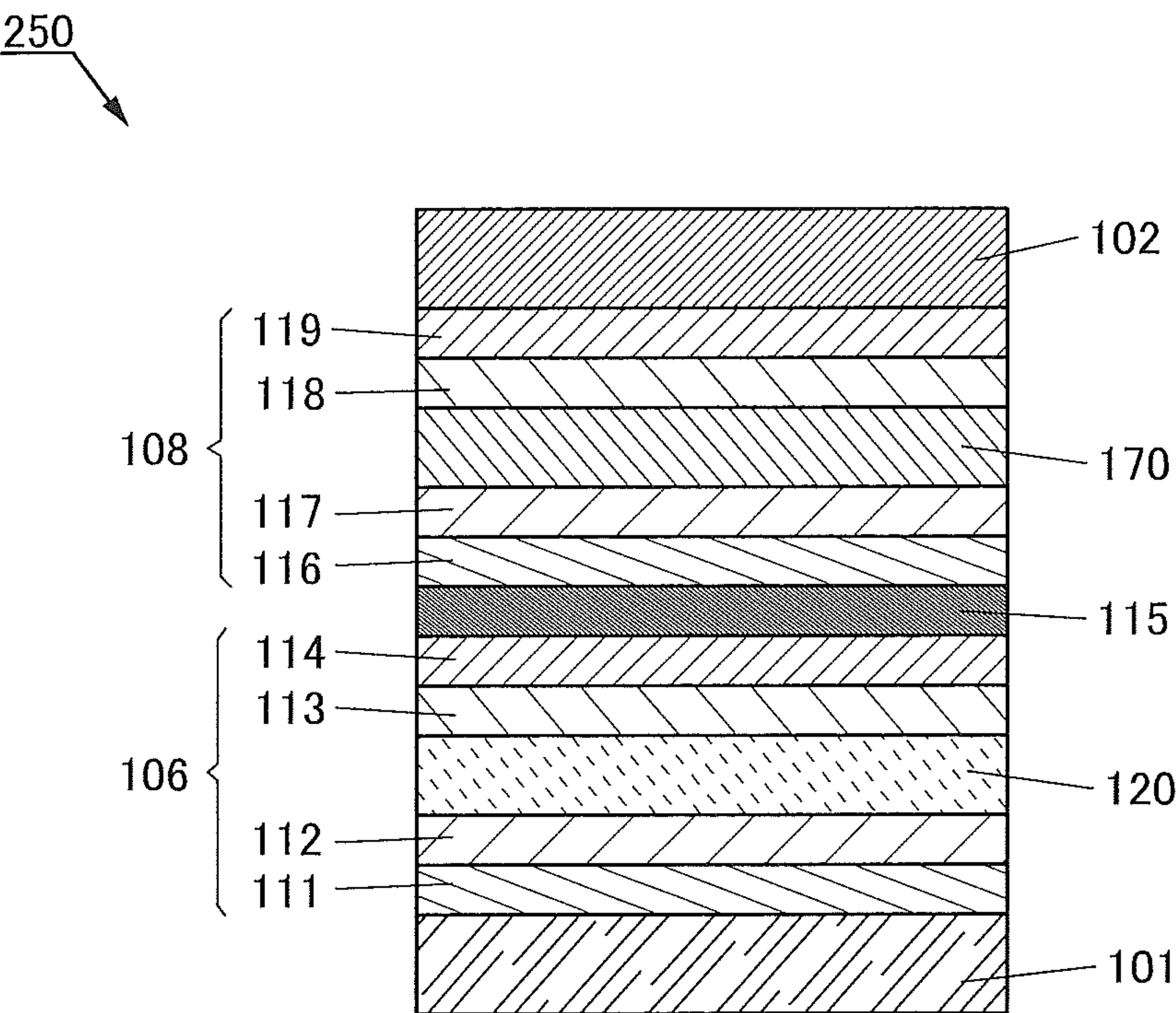


FIG. 3B

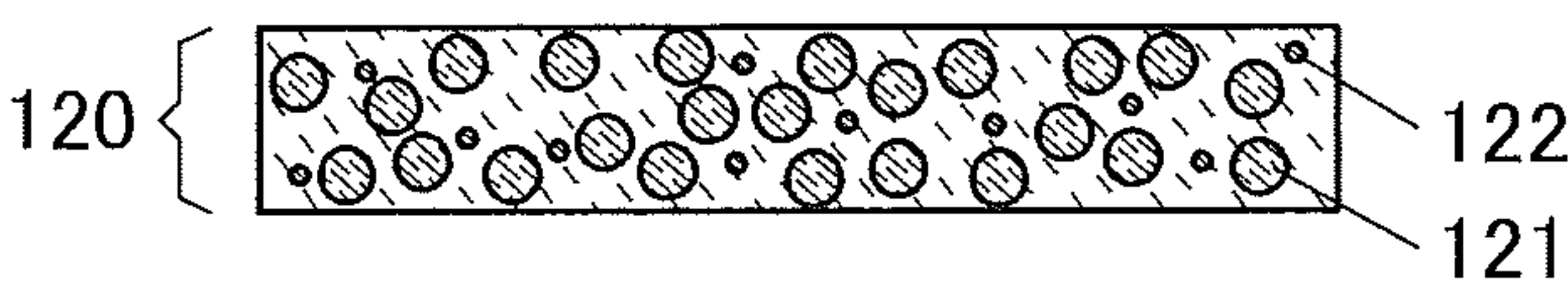


FIG. 3C

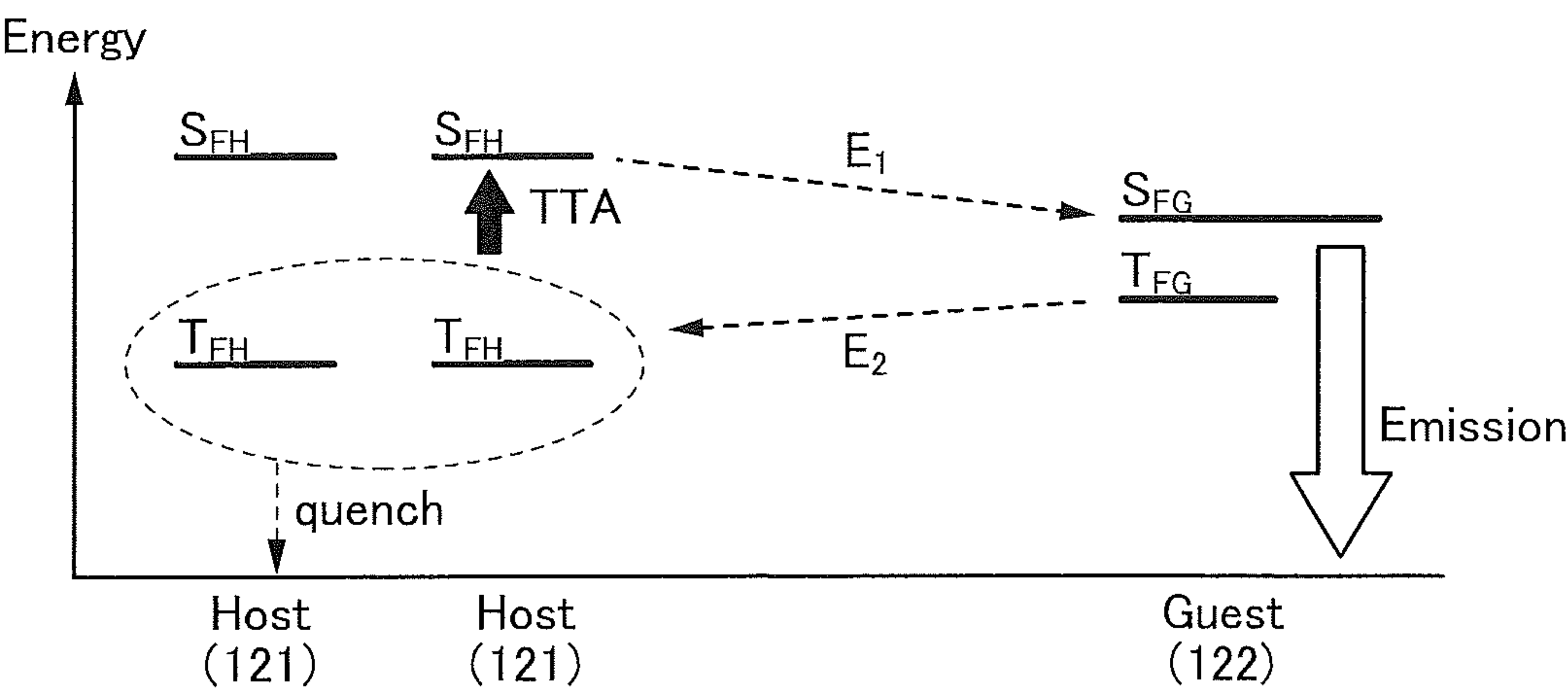


FIG. 4A

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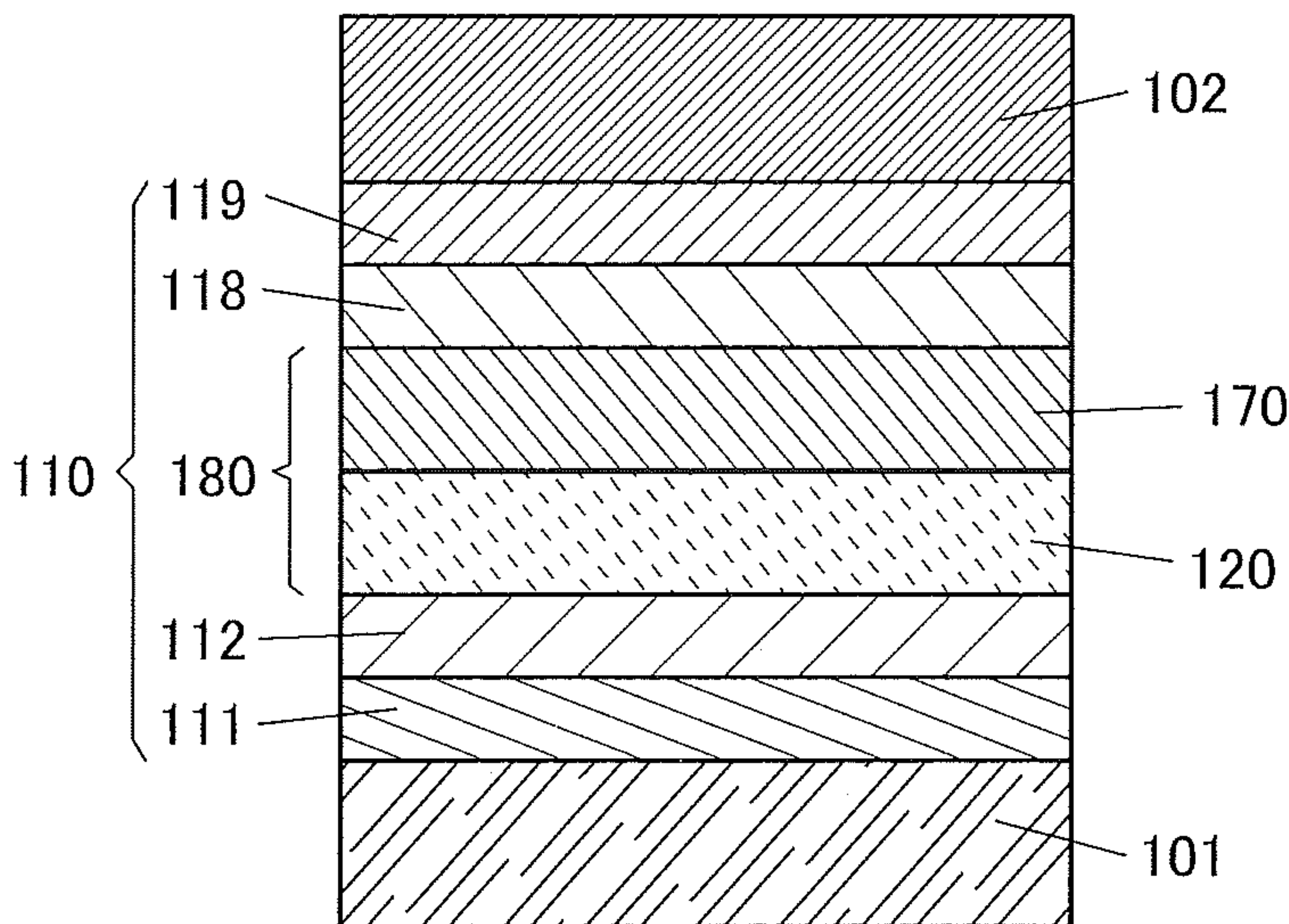


FIG. 4B

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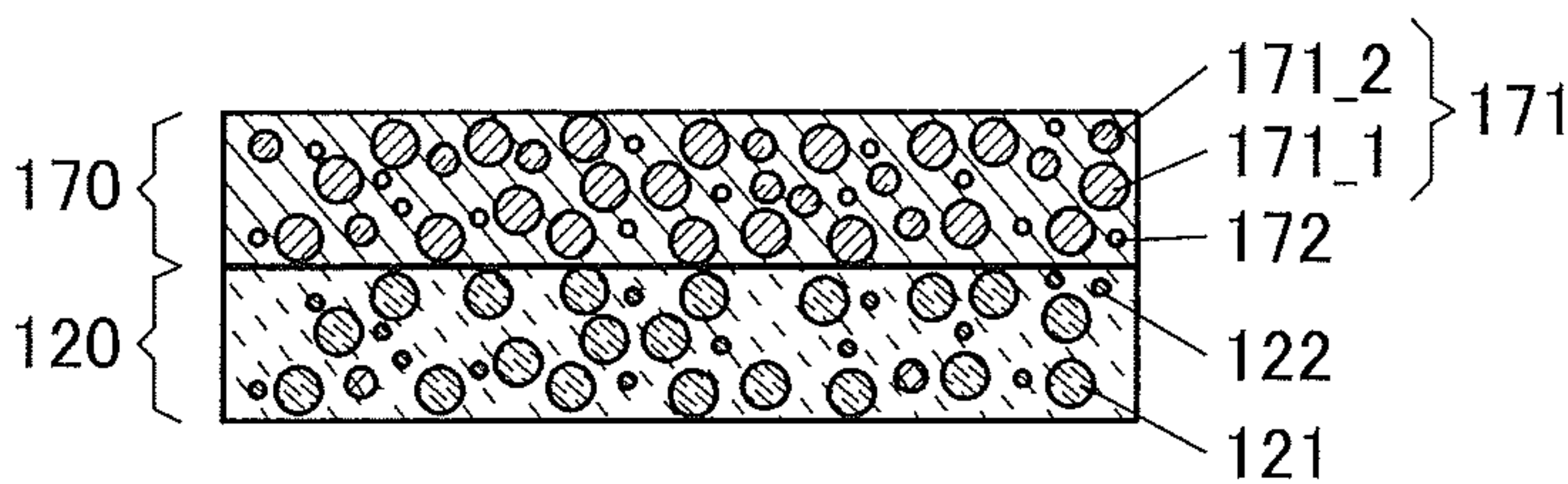


FIG. 4C

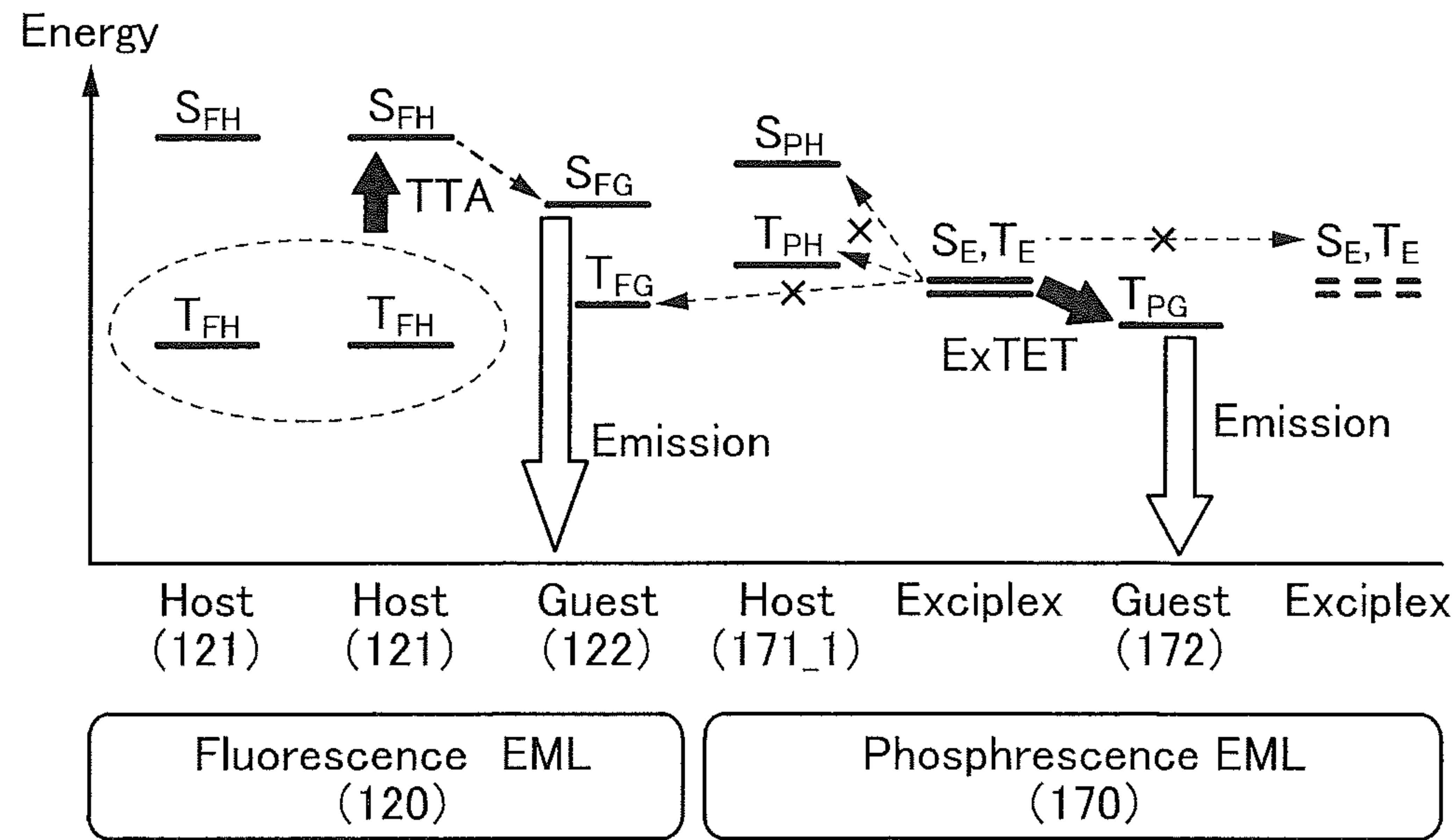


FIG. 5A

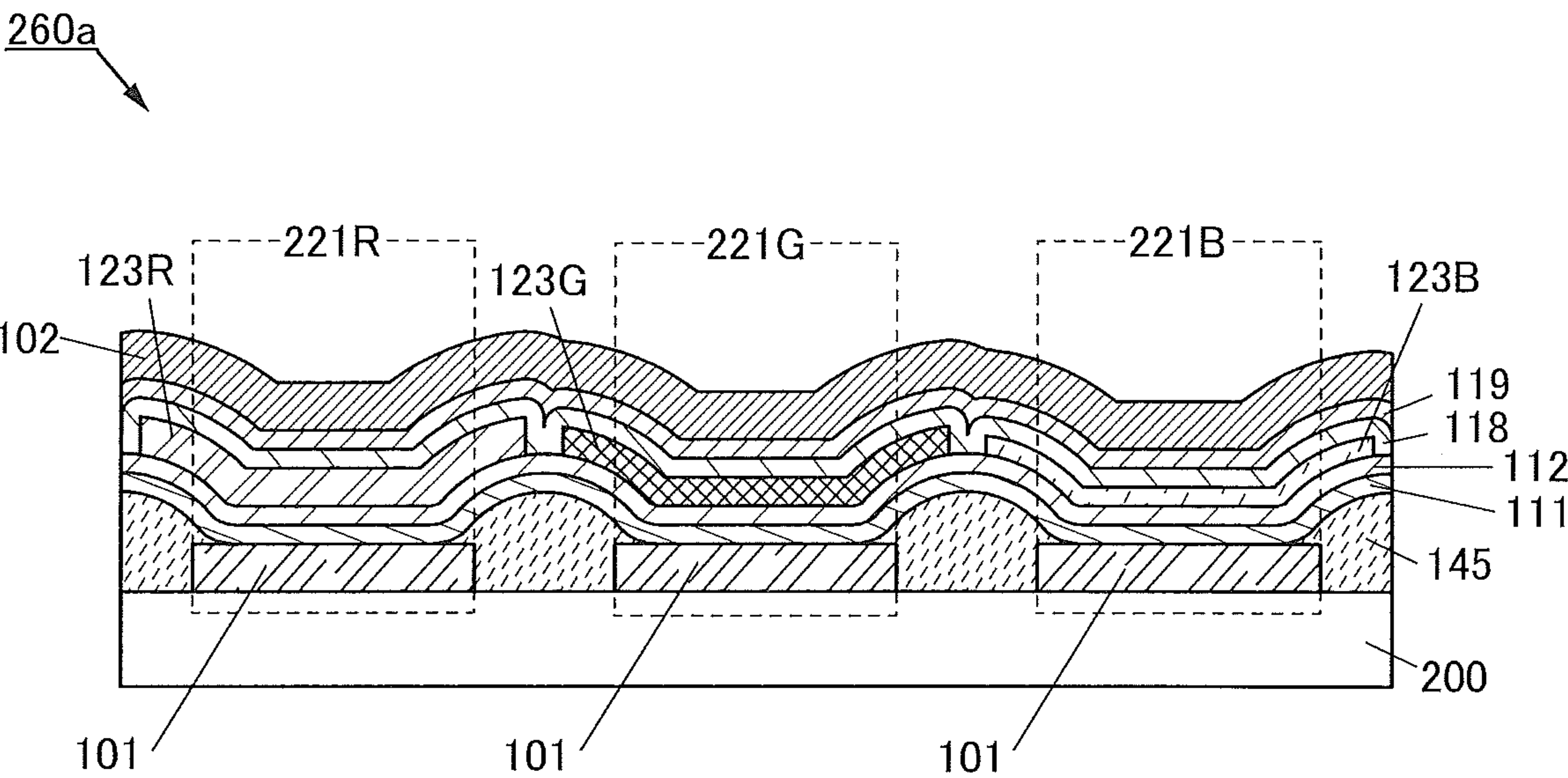


FIG. 5B

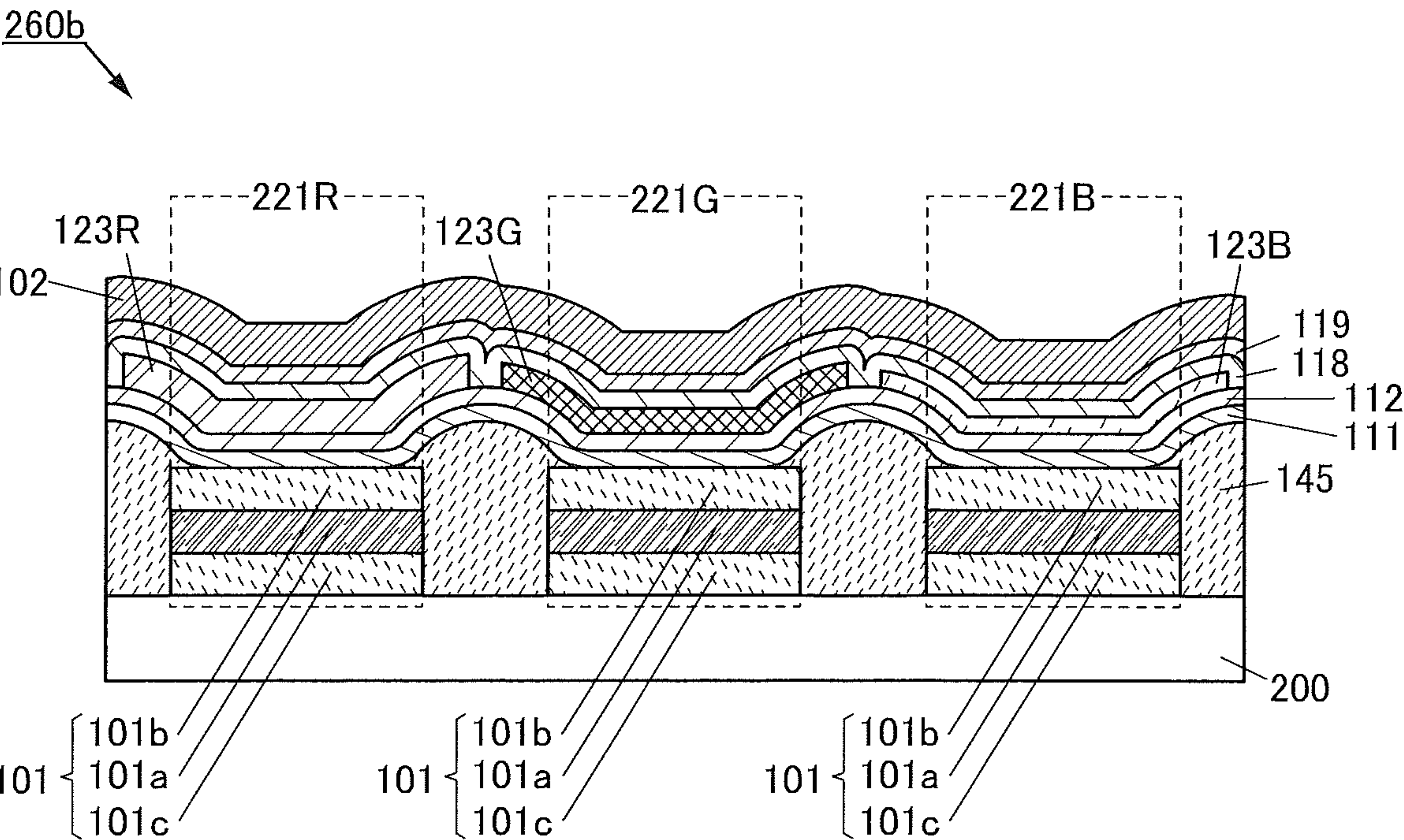


FIG. 6A

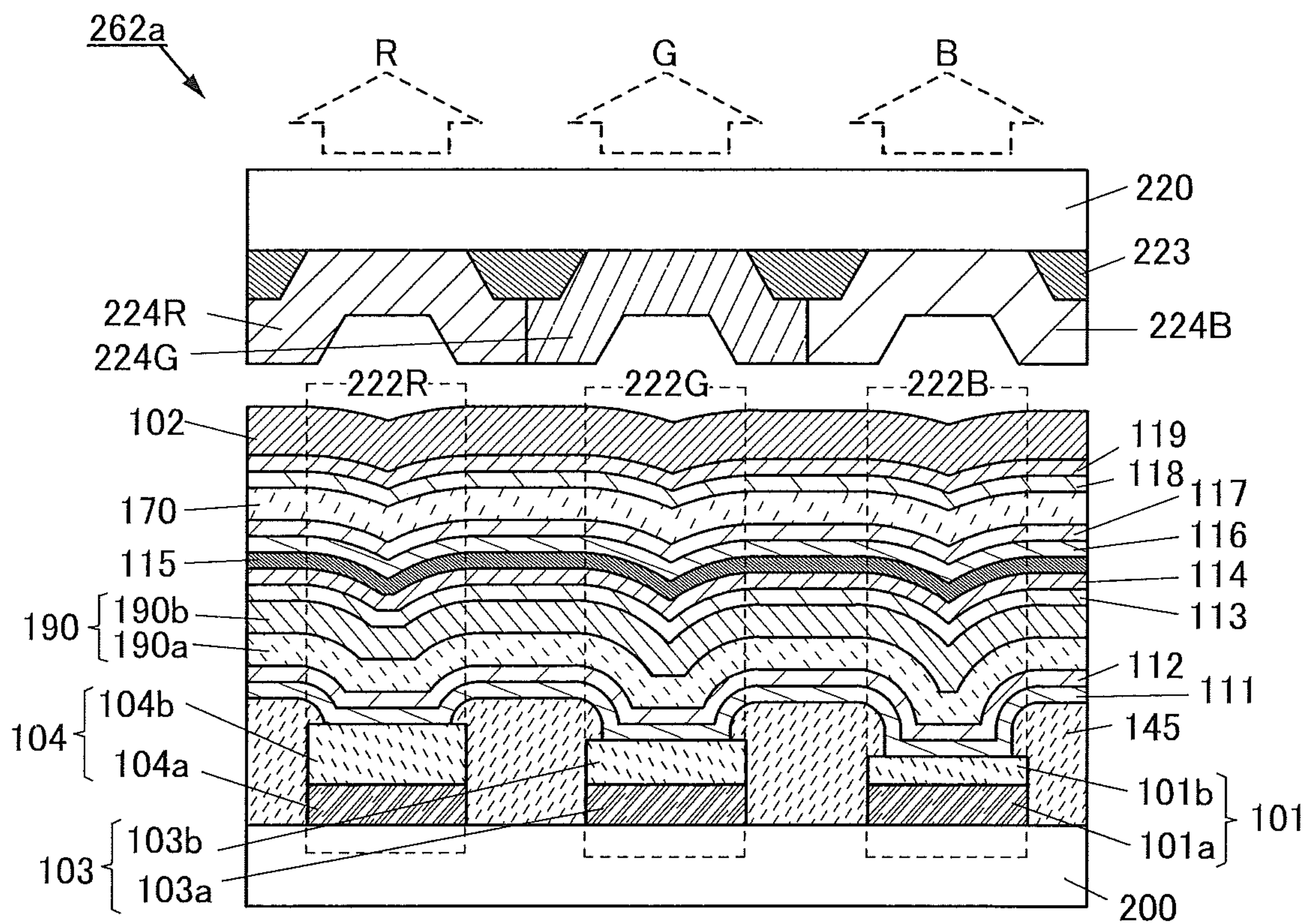


FIG. 6B

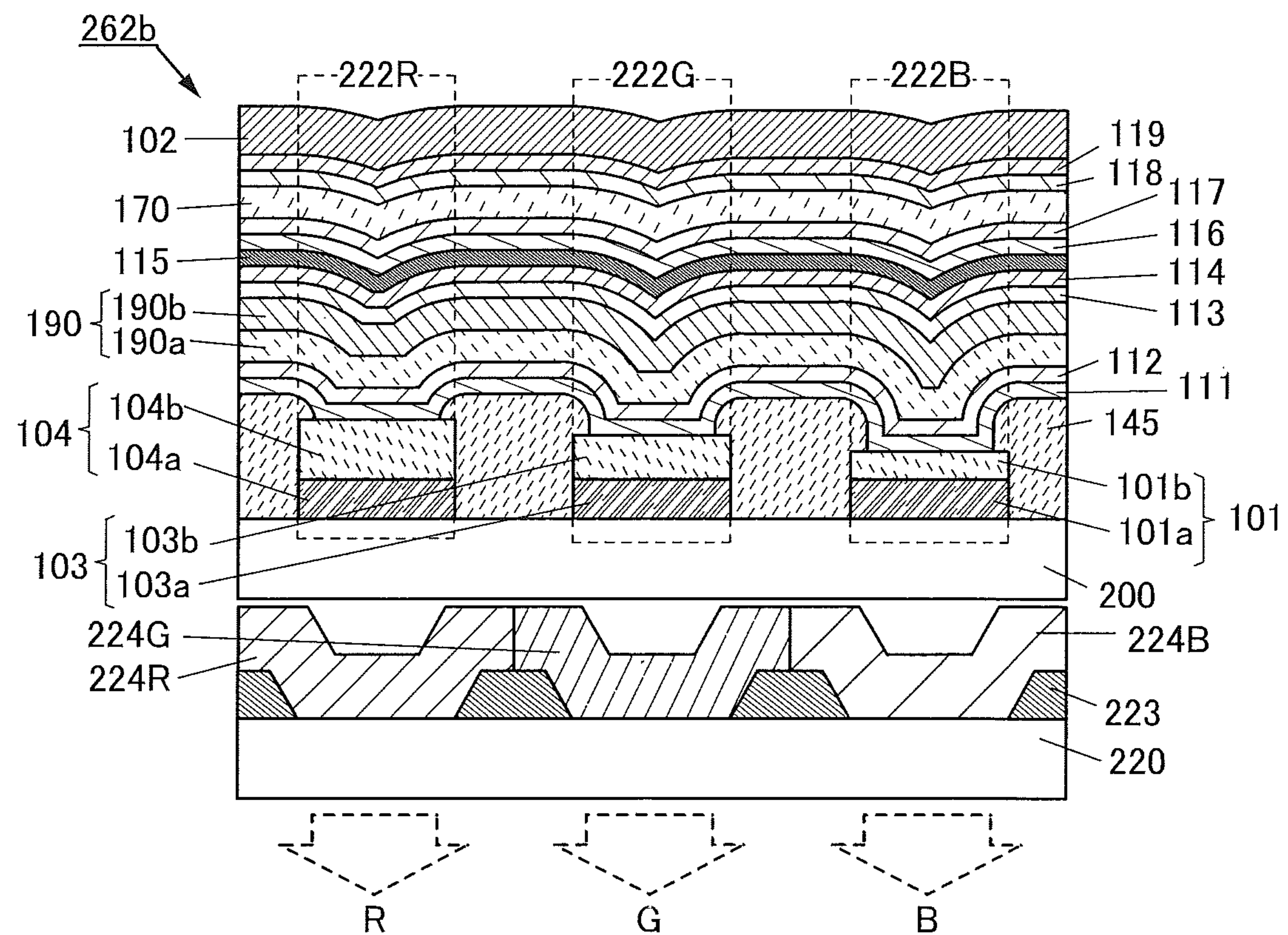


FIG. 7A

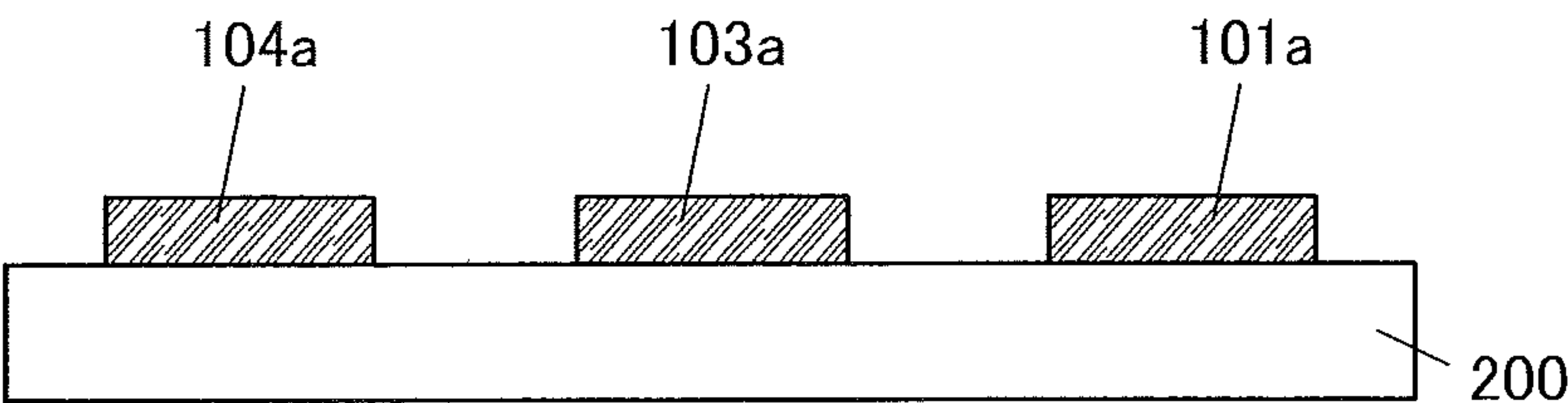


FIG. 7B

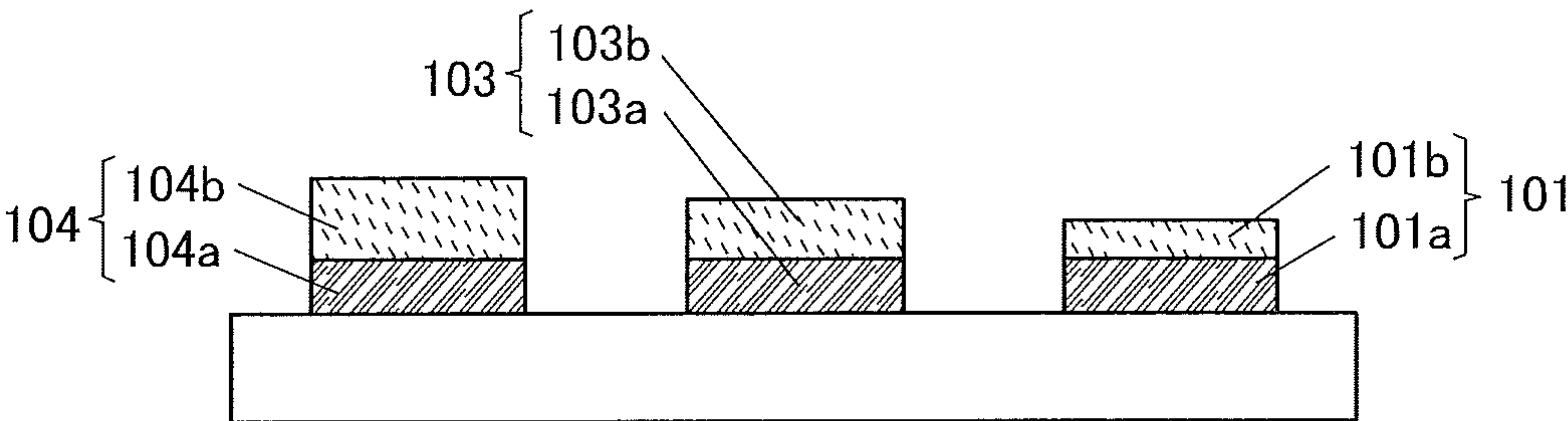


FIG. 7C

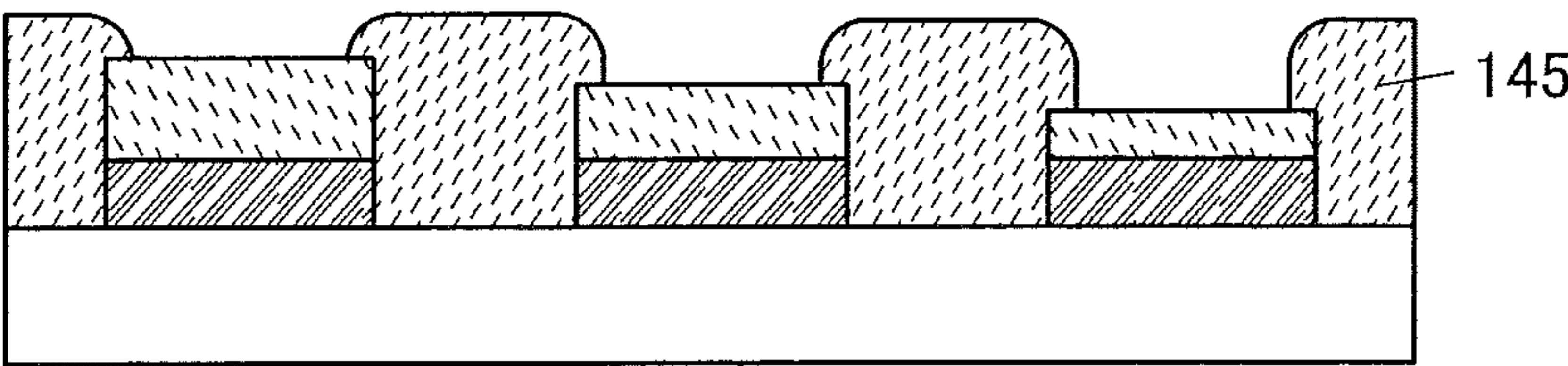


FIG. 8A

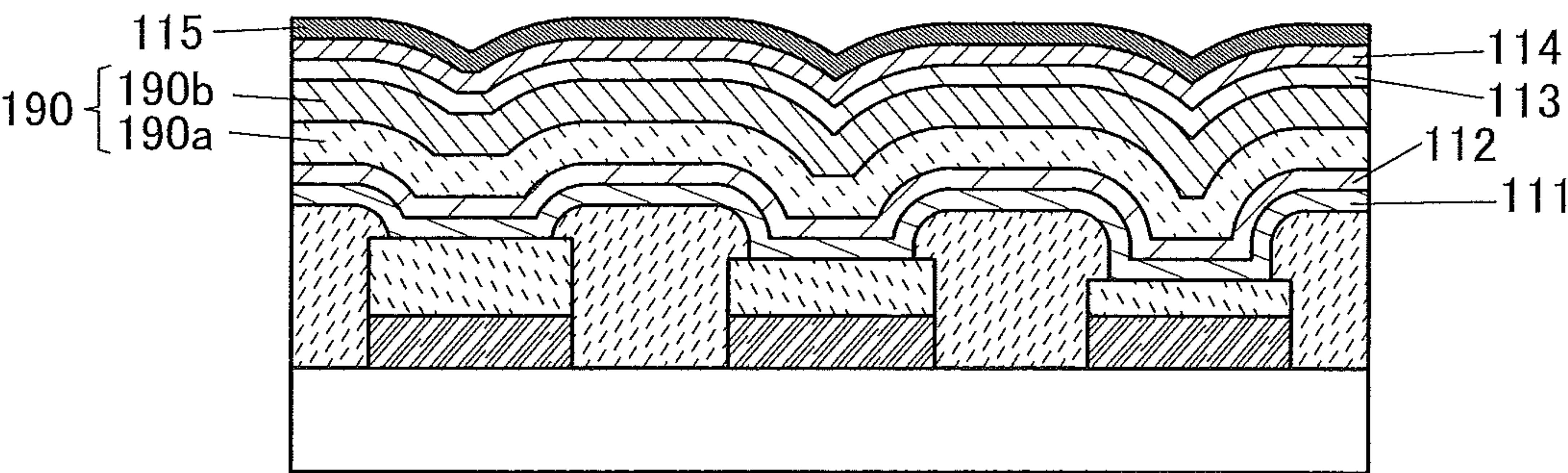


FIG. 8B

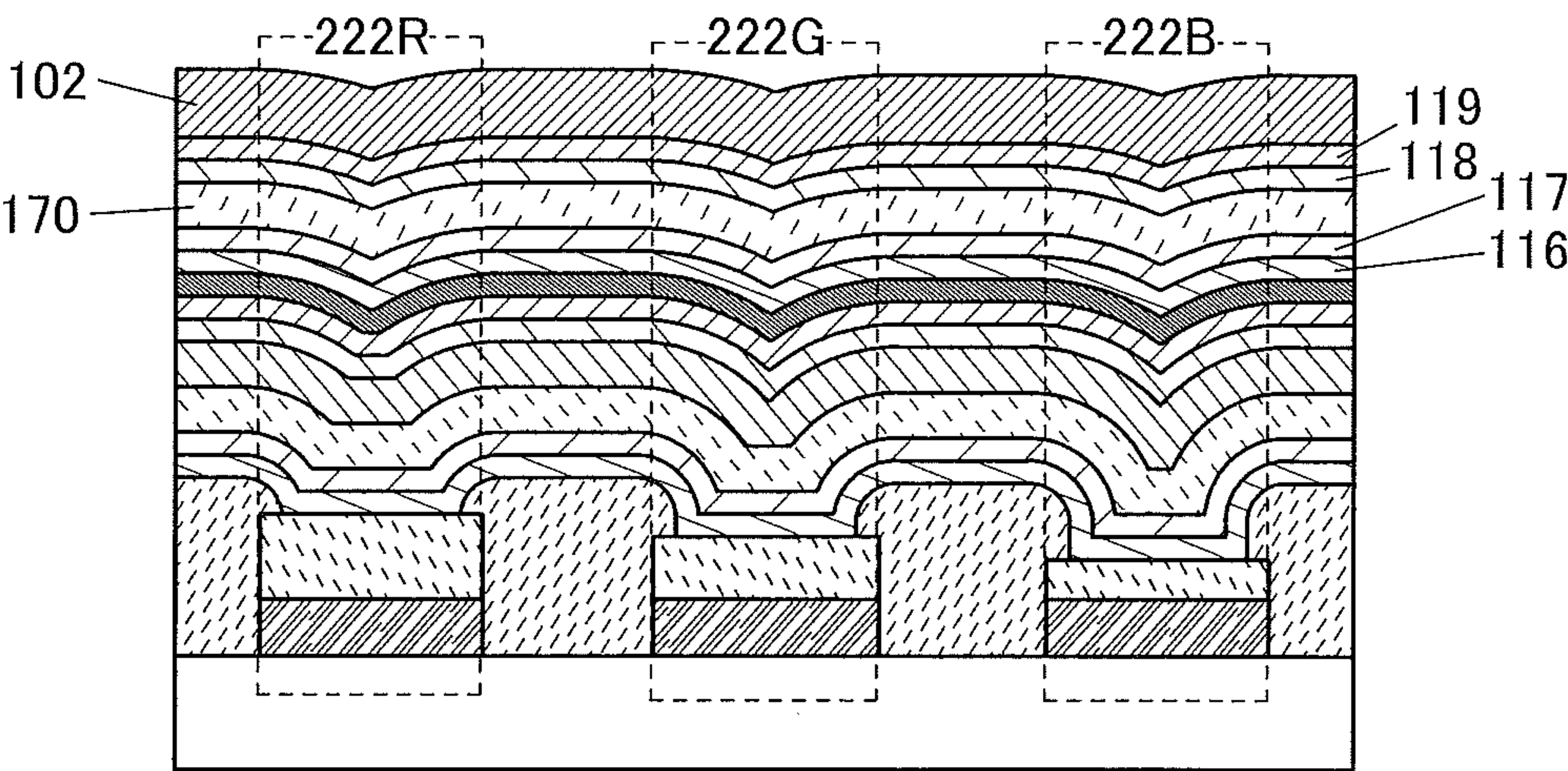


FIG. 8C

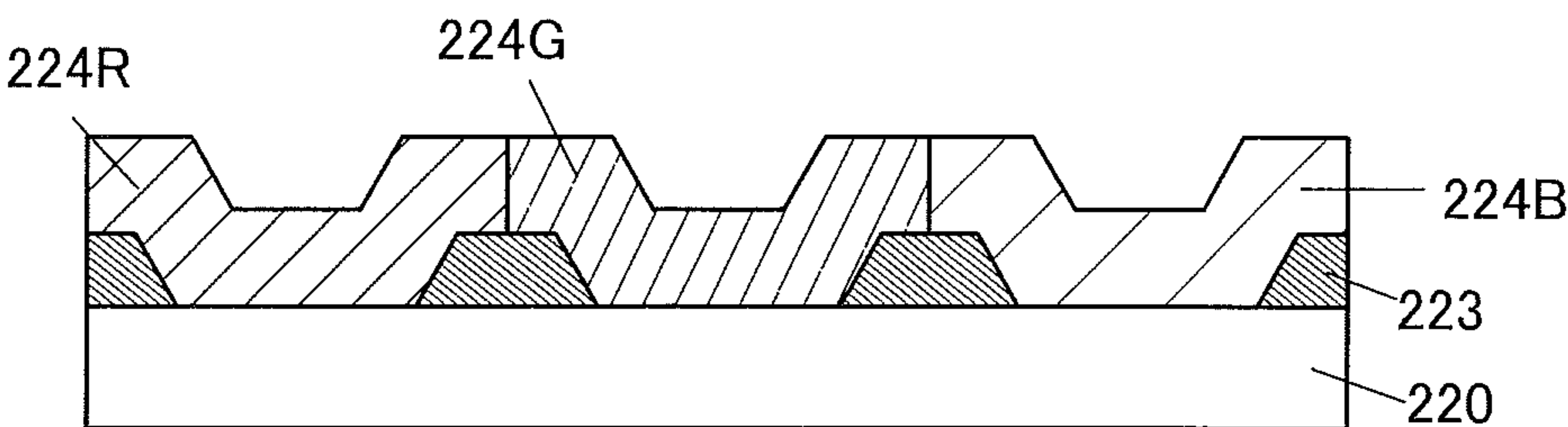


FIG. 9A

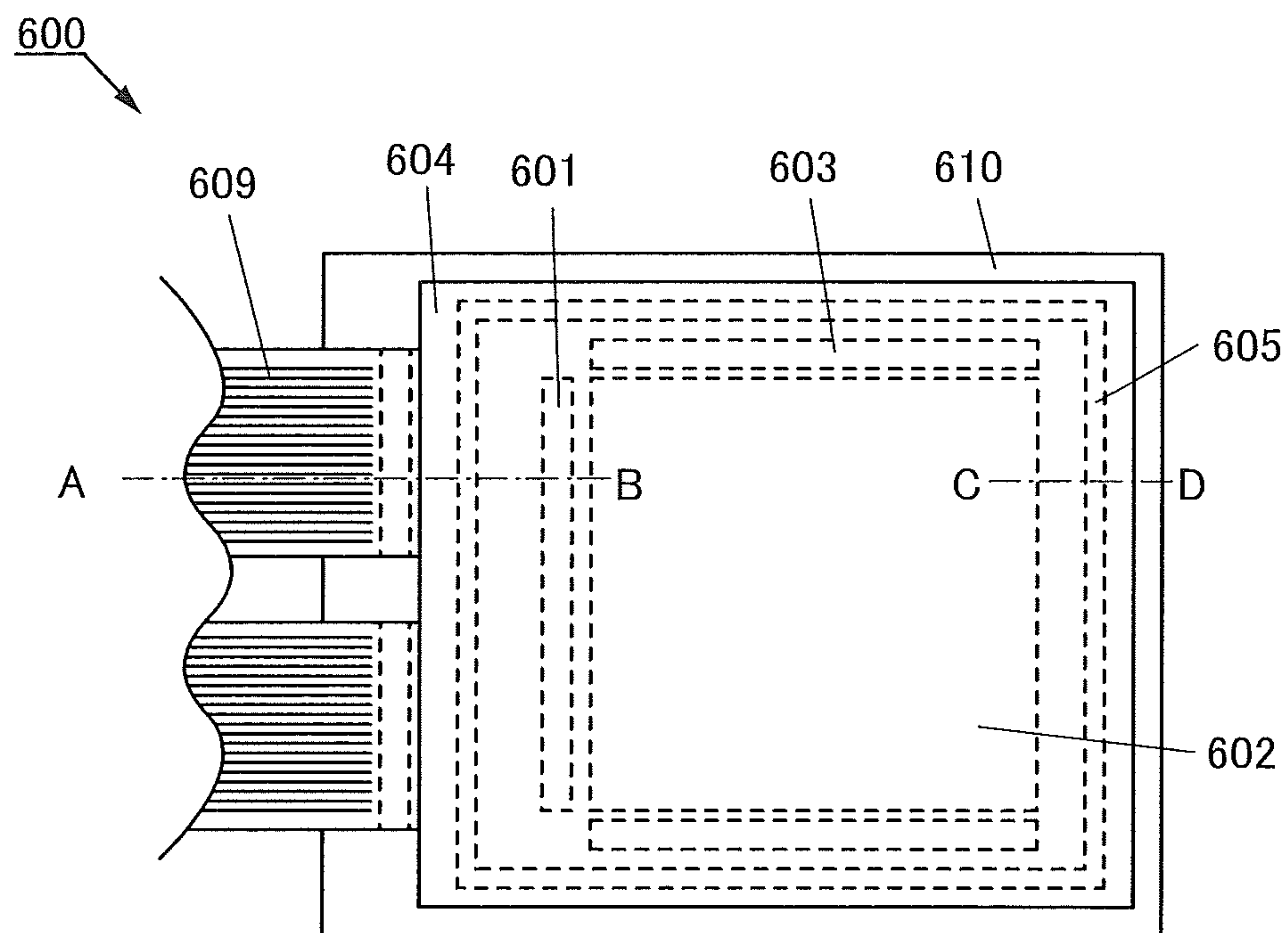


FIG. 9B

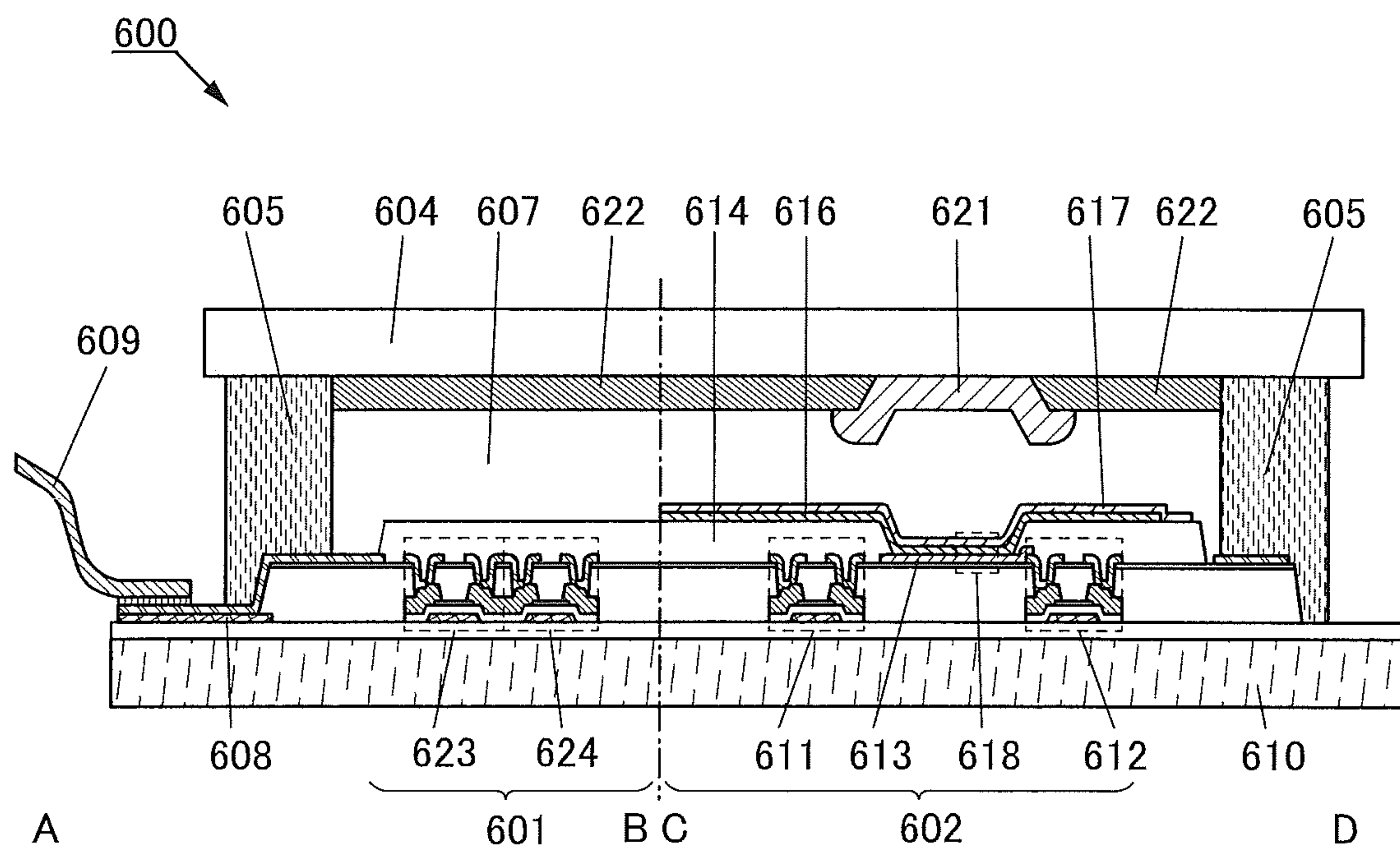


FIG. 10A

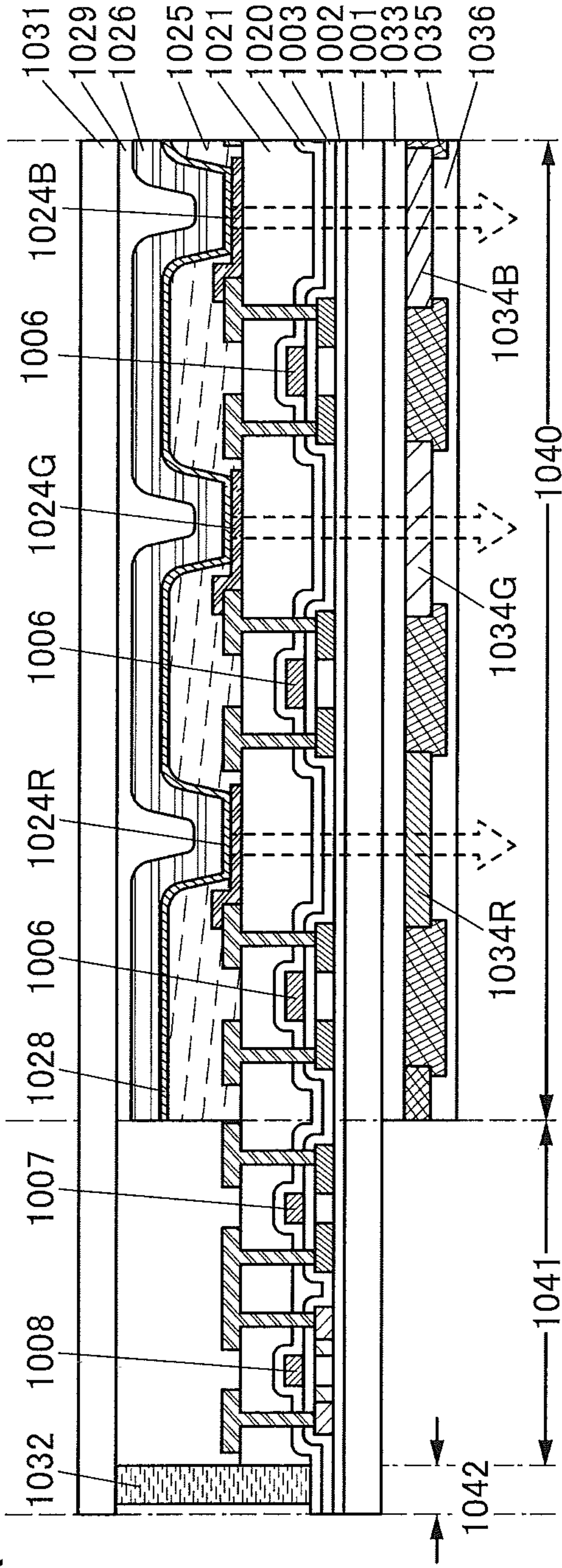


FIG. 10B

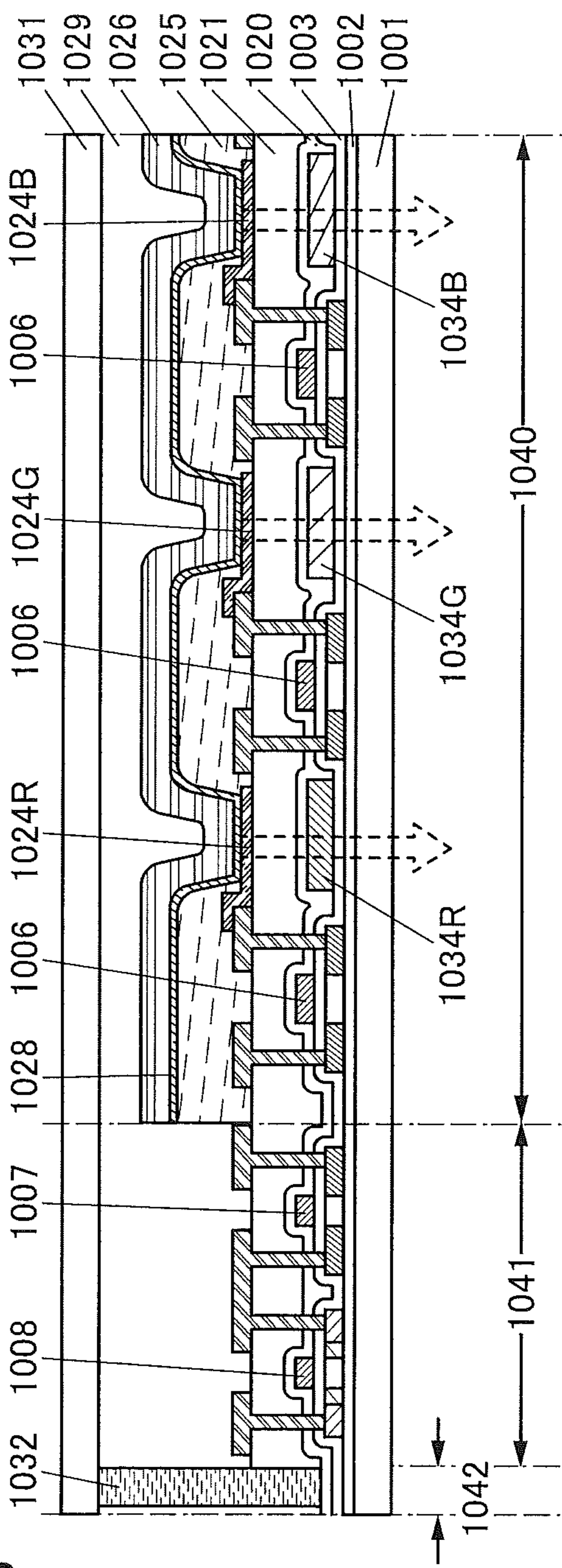


FIG. 11

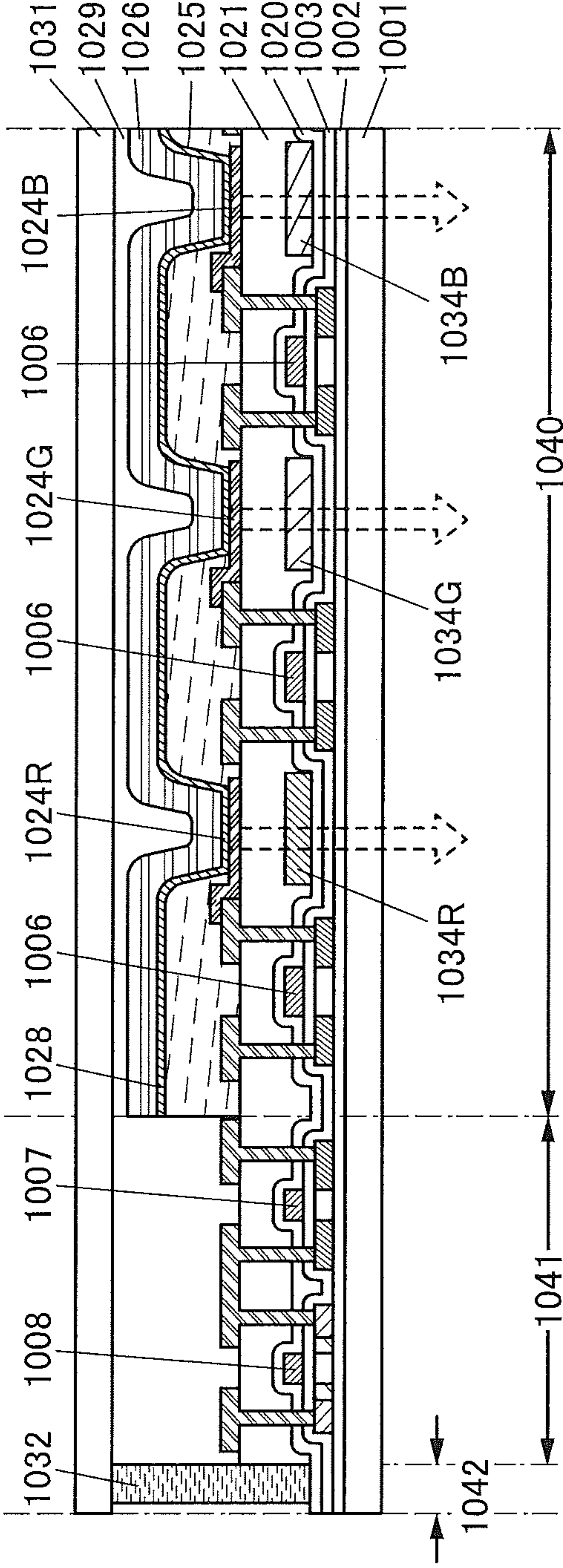


FIG. 12A

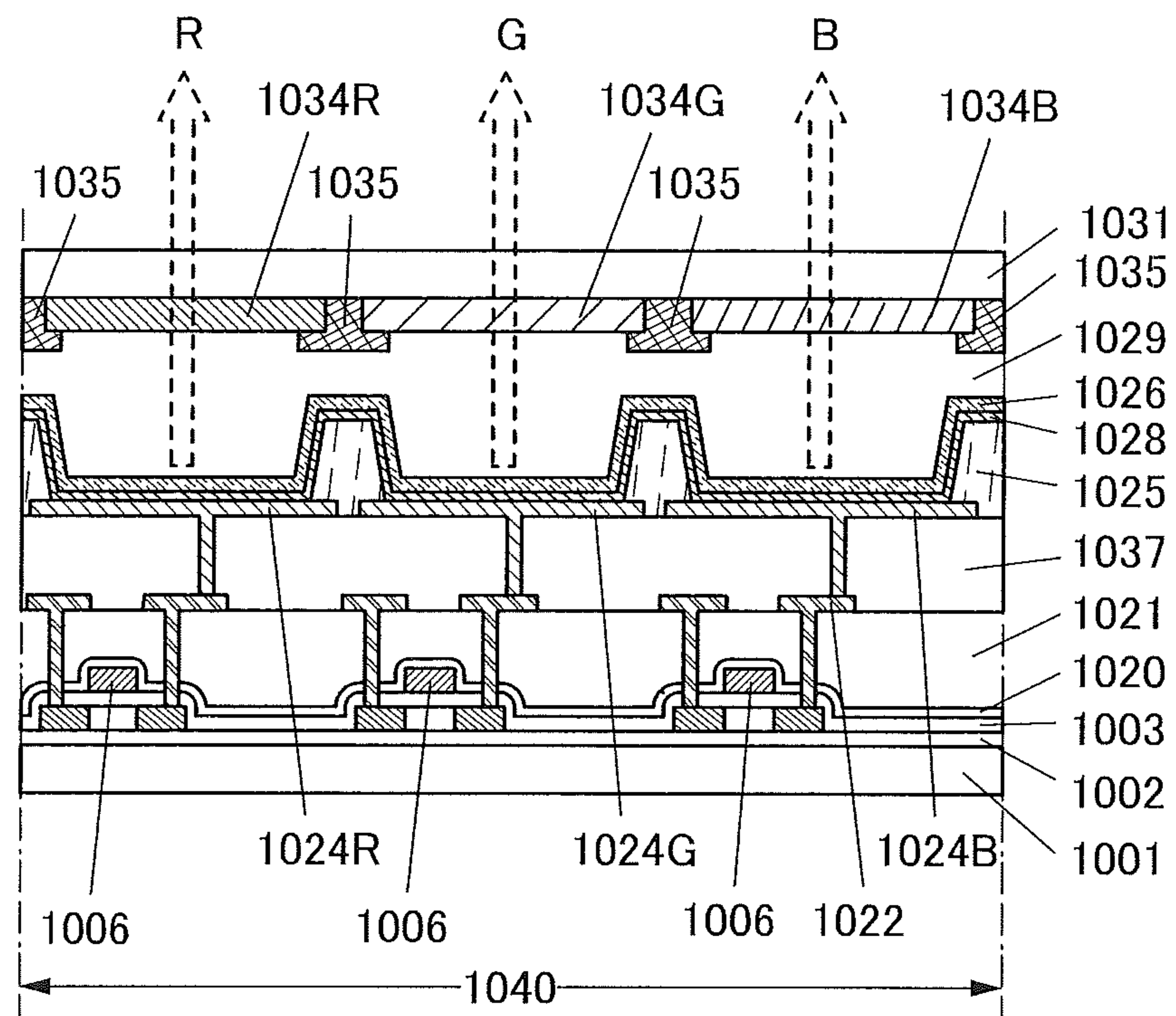


FIG. 12B

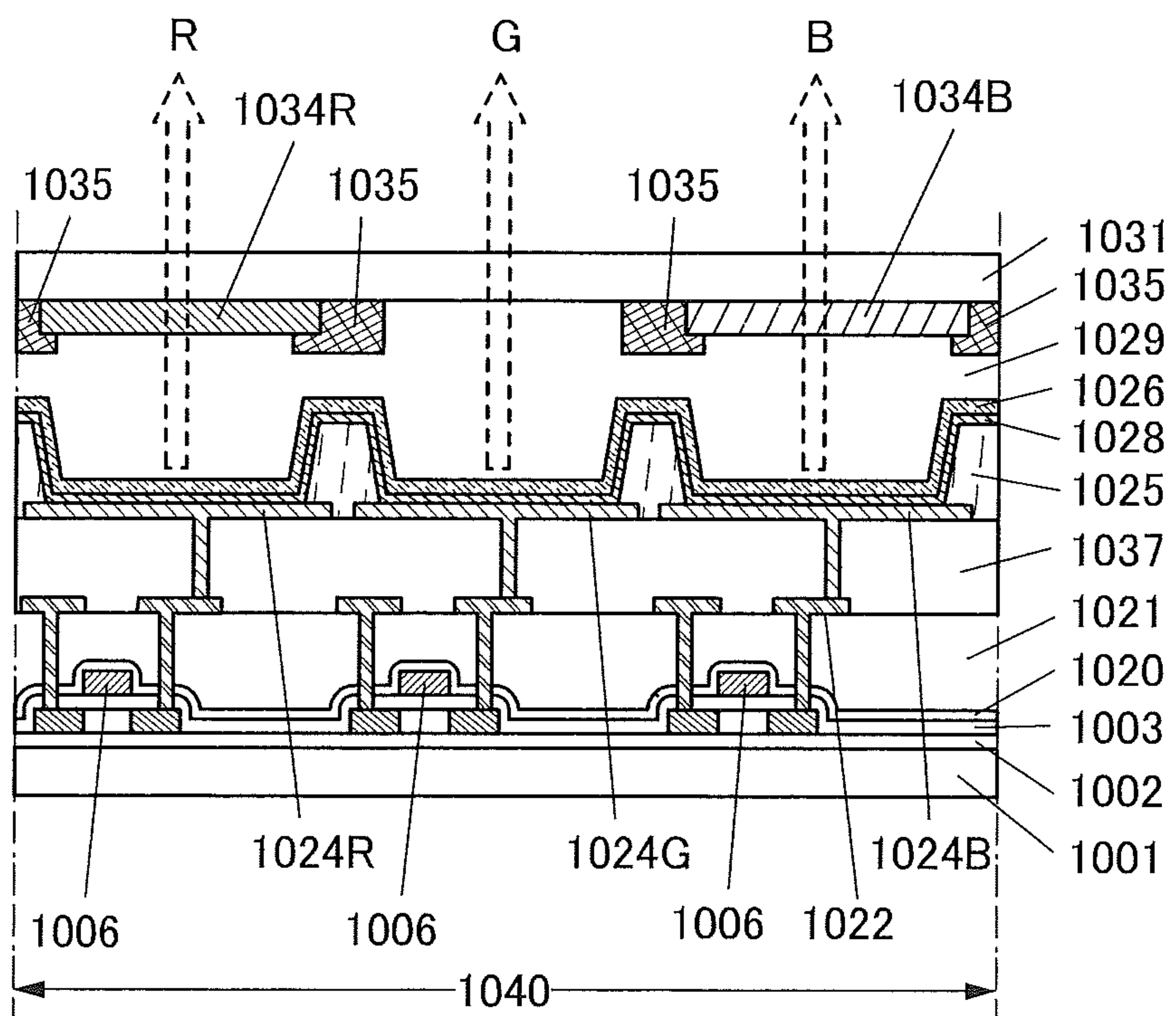


FIG. 13A

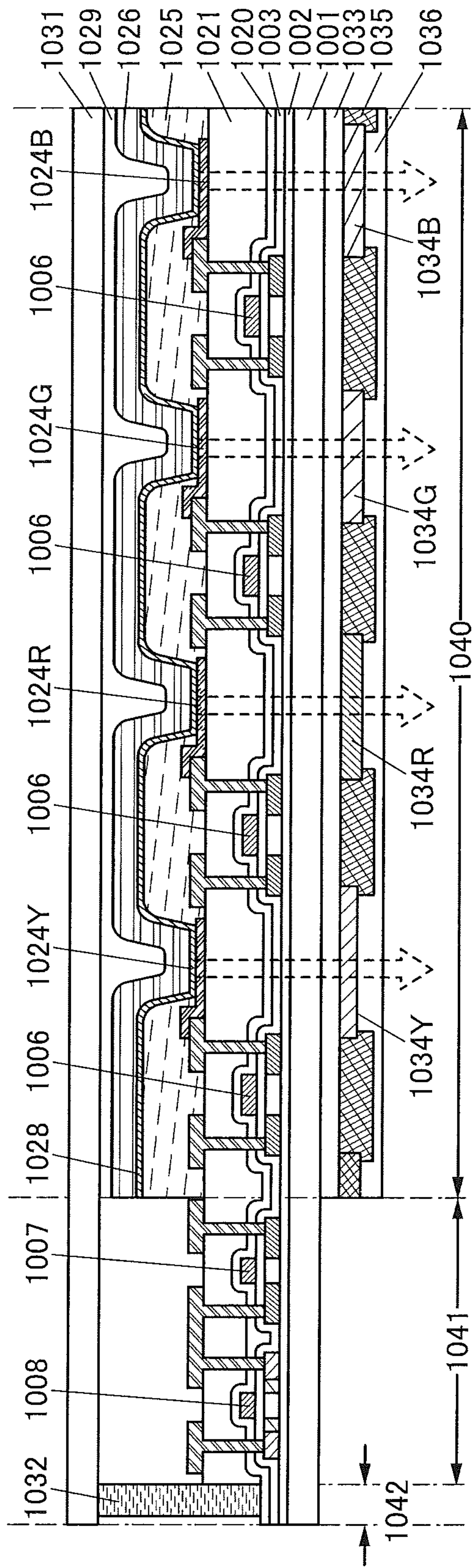


FIG. 13B

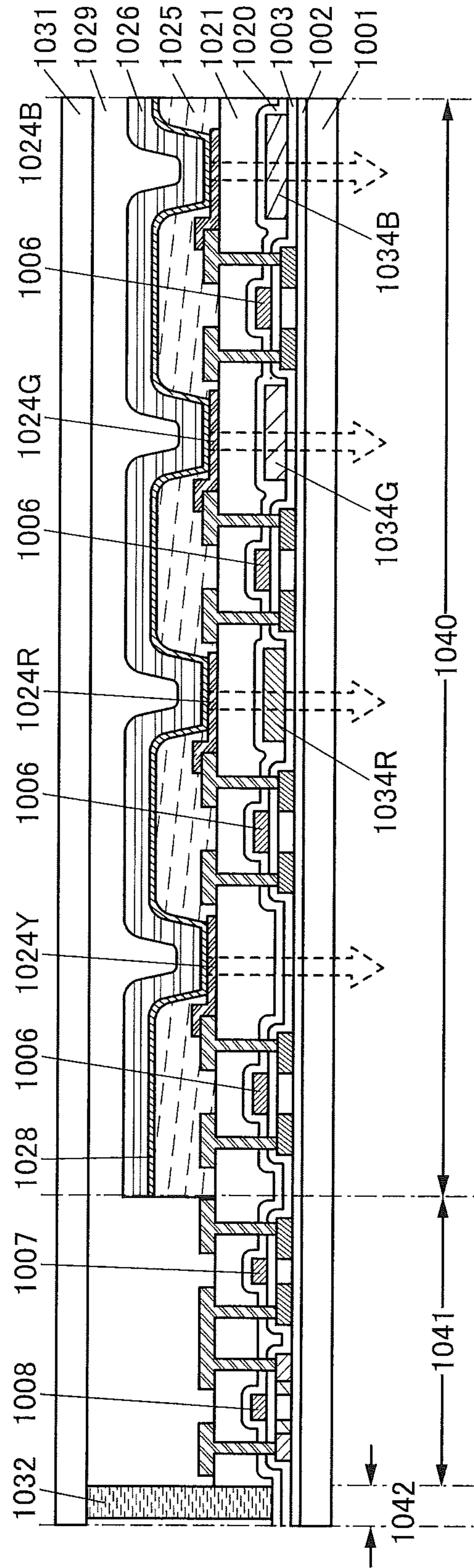


FIG. 14

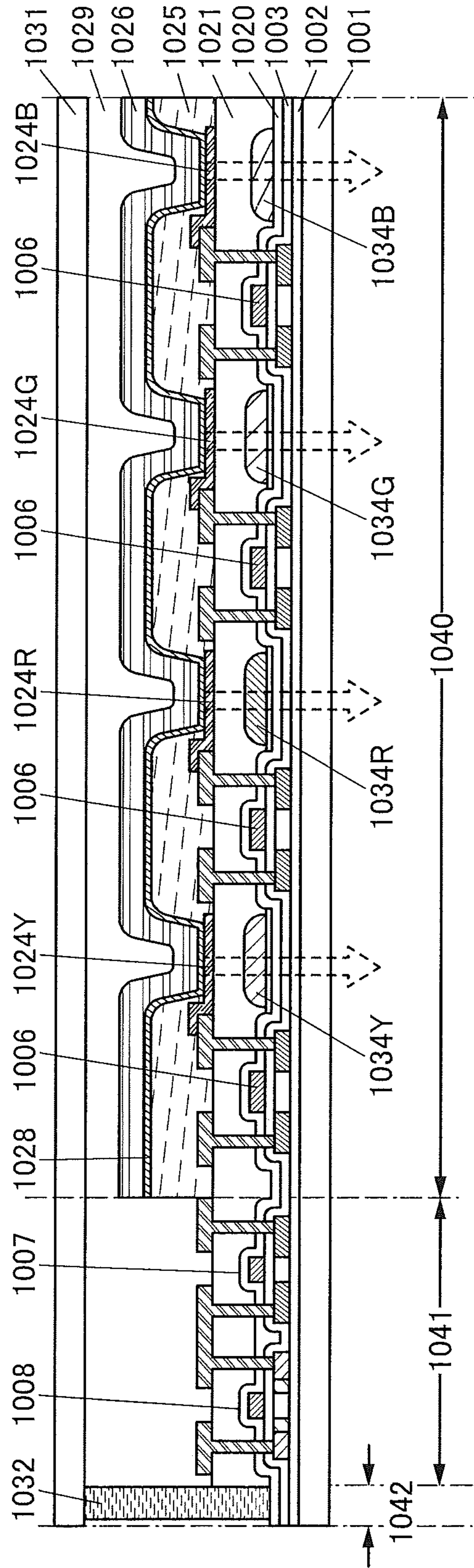


FIG. 15A

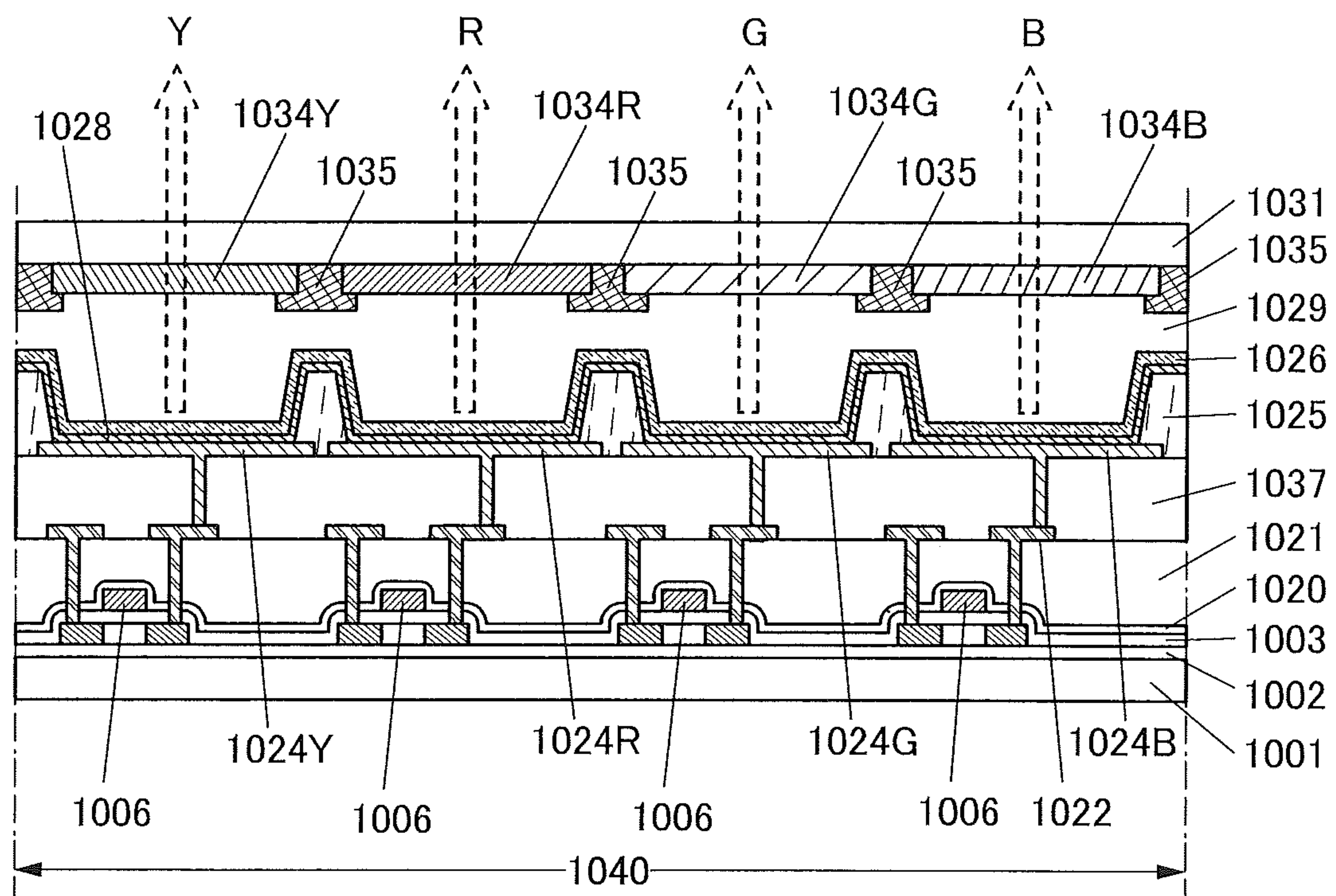


FIG. 15B

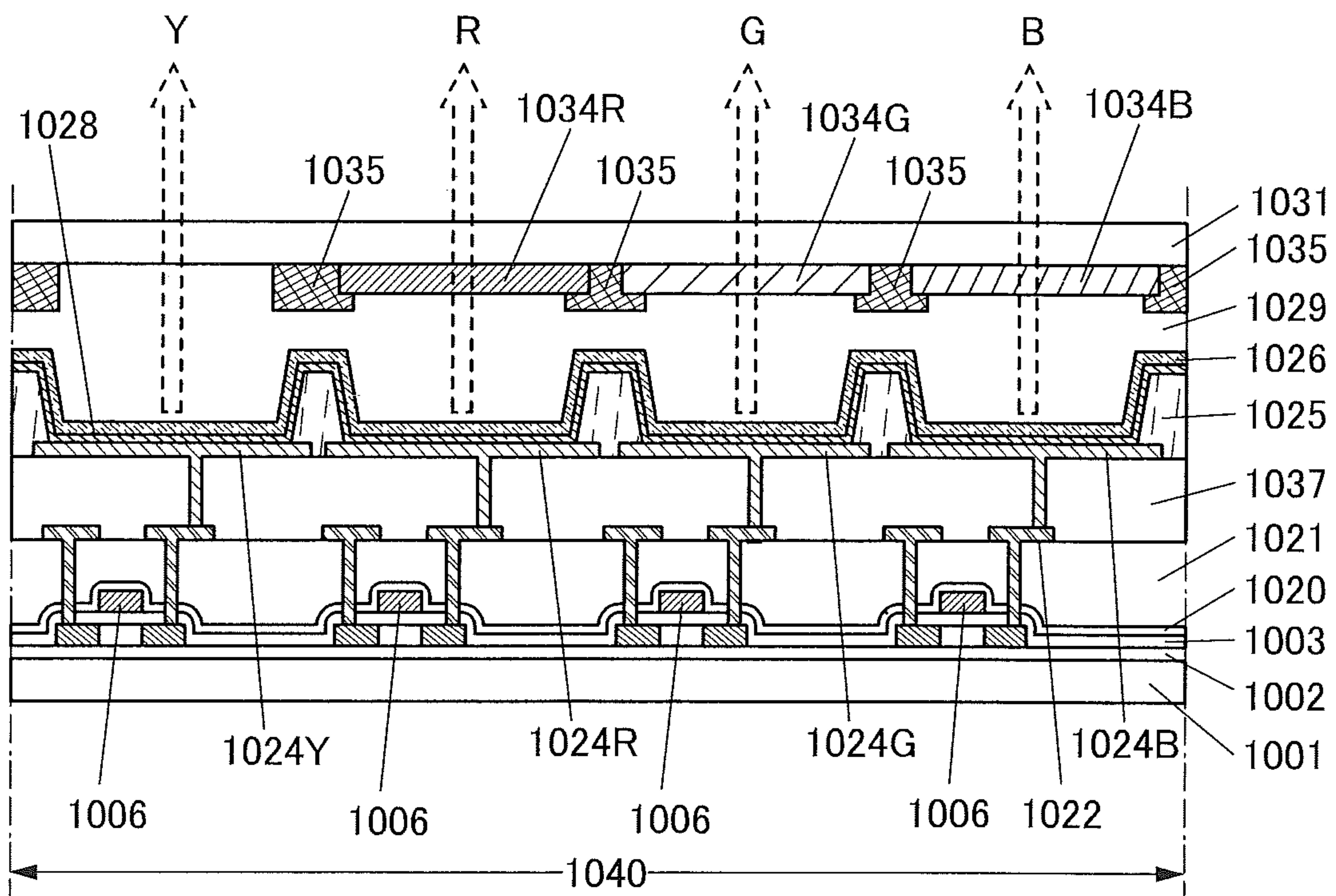


FIG. 16

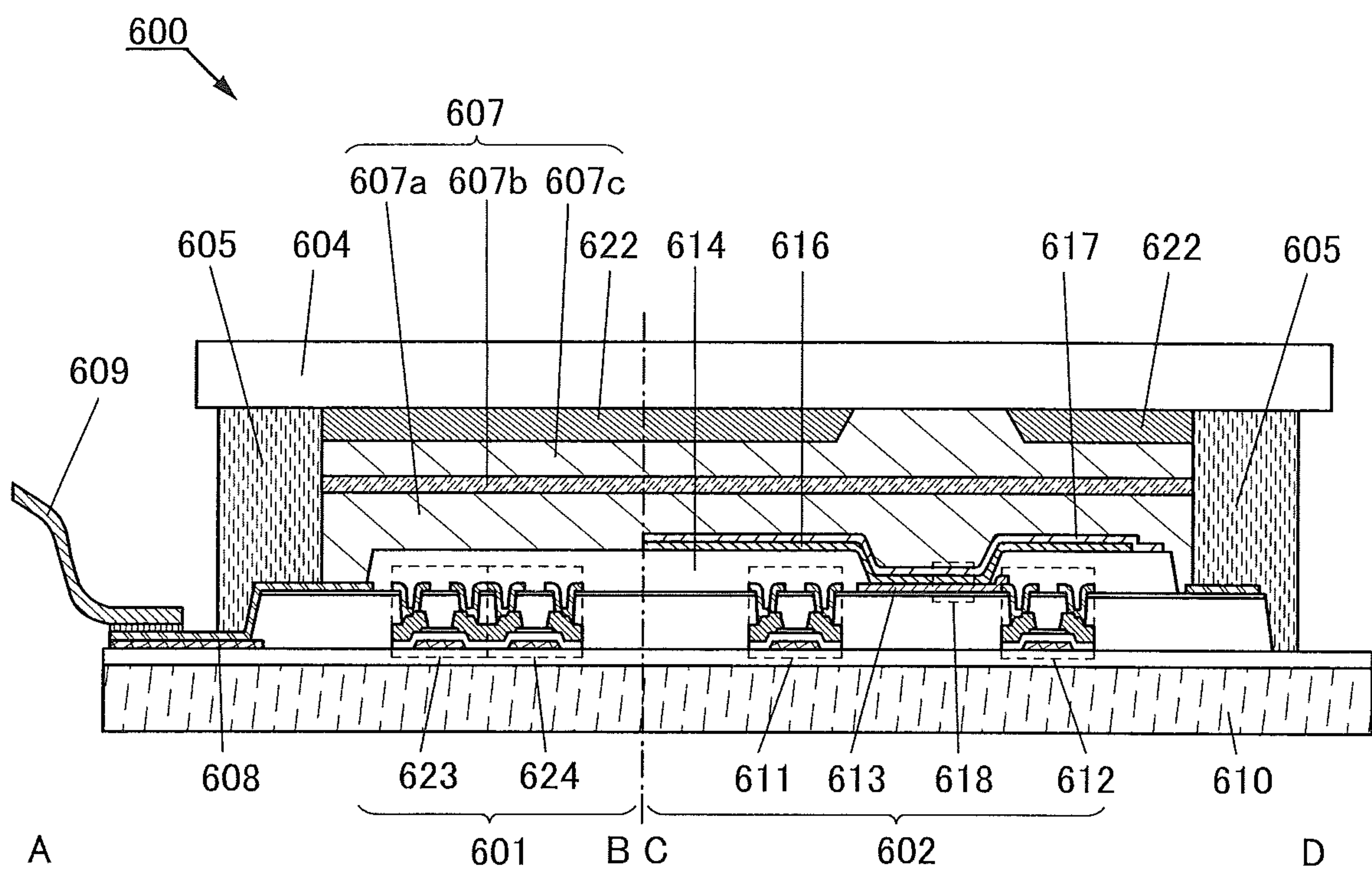


FIG. 17A

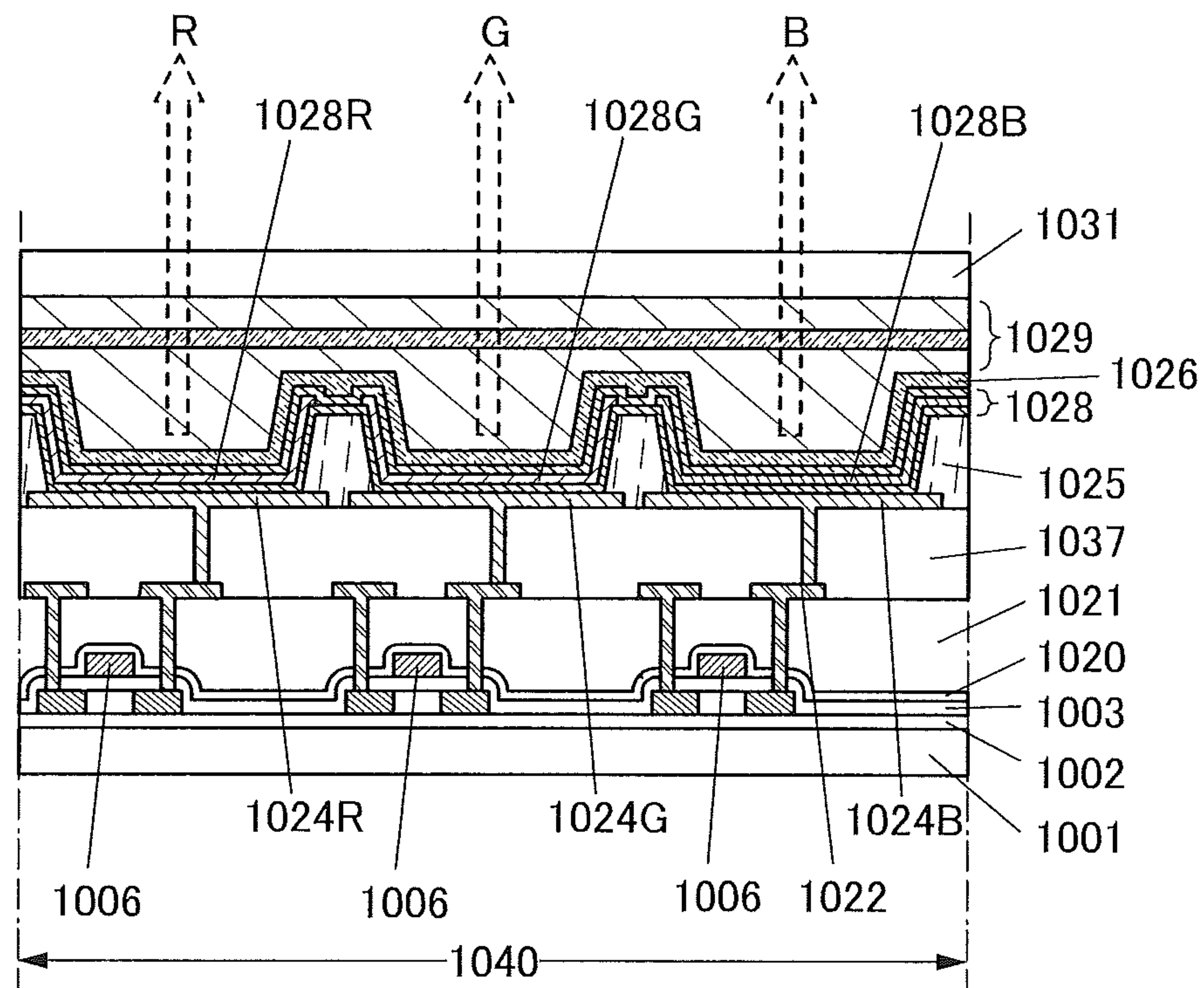


FIG. 17B

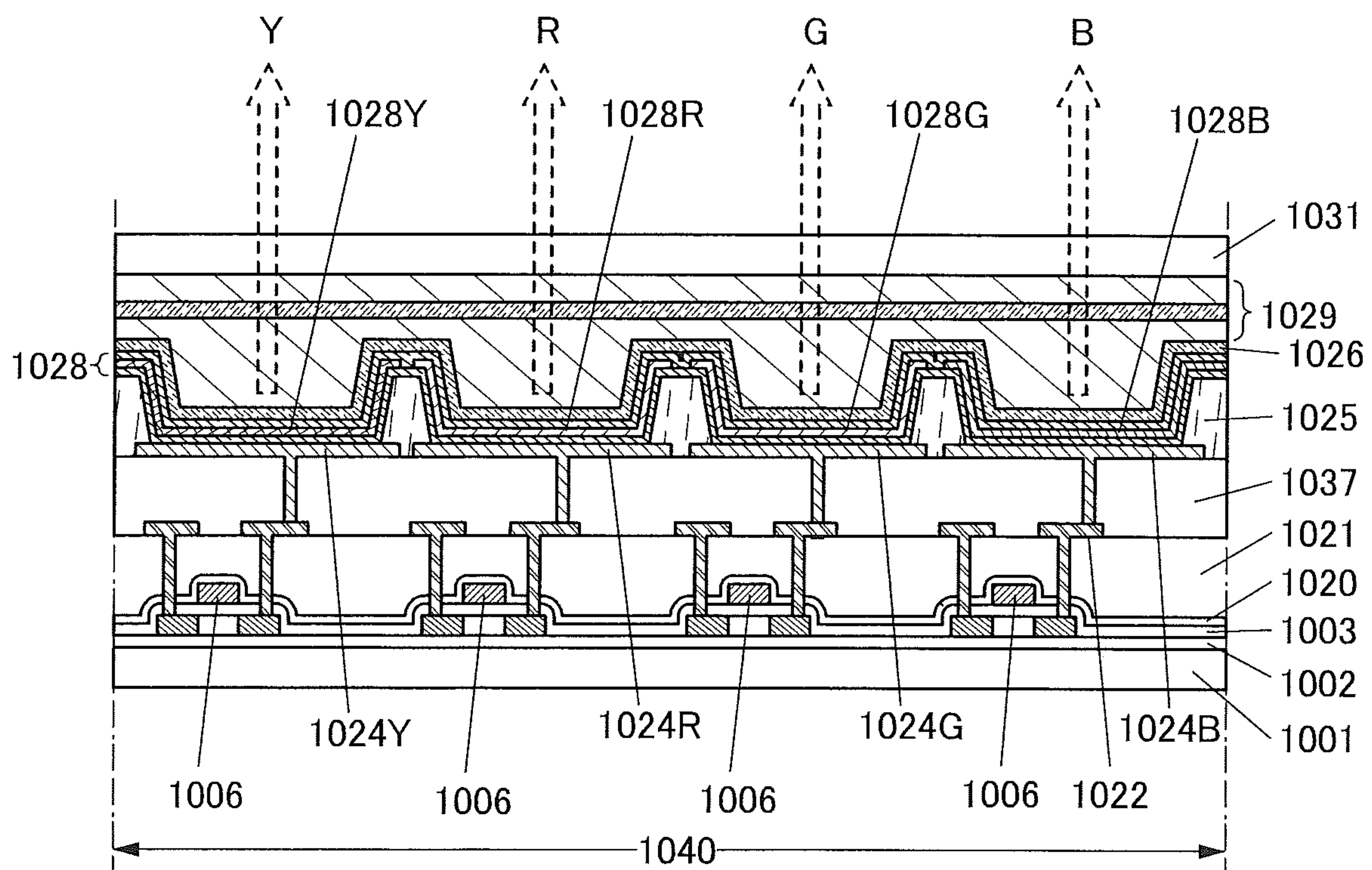


FIG. 18A

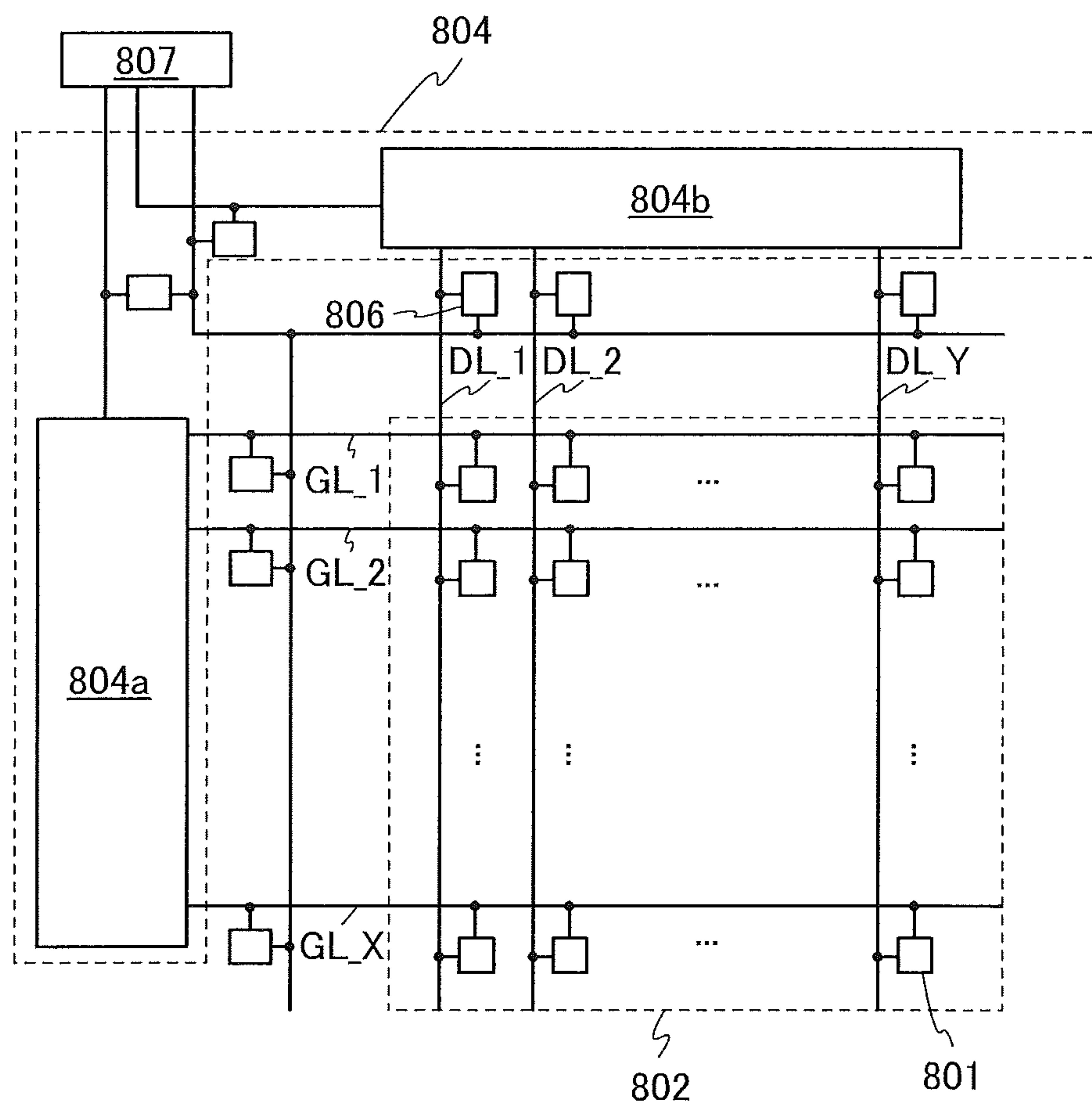


FIG. 18B

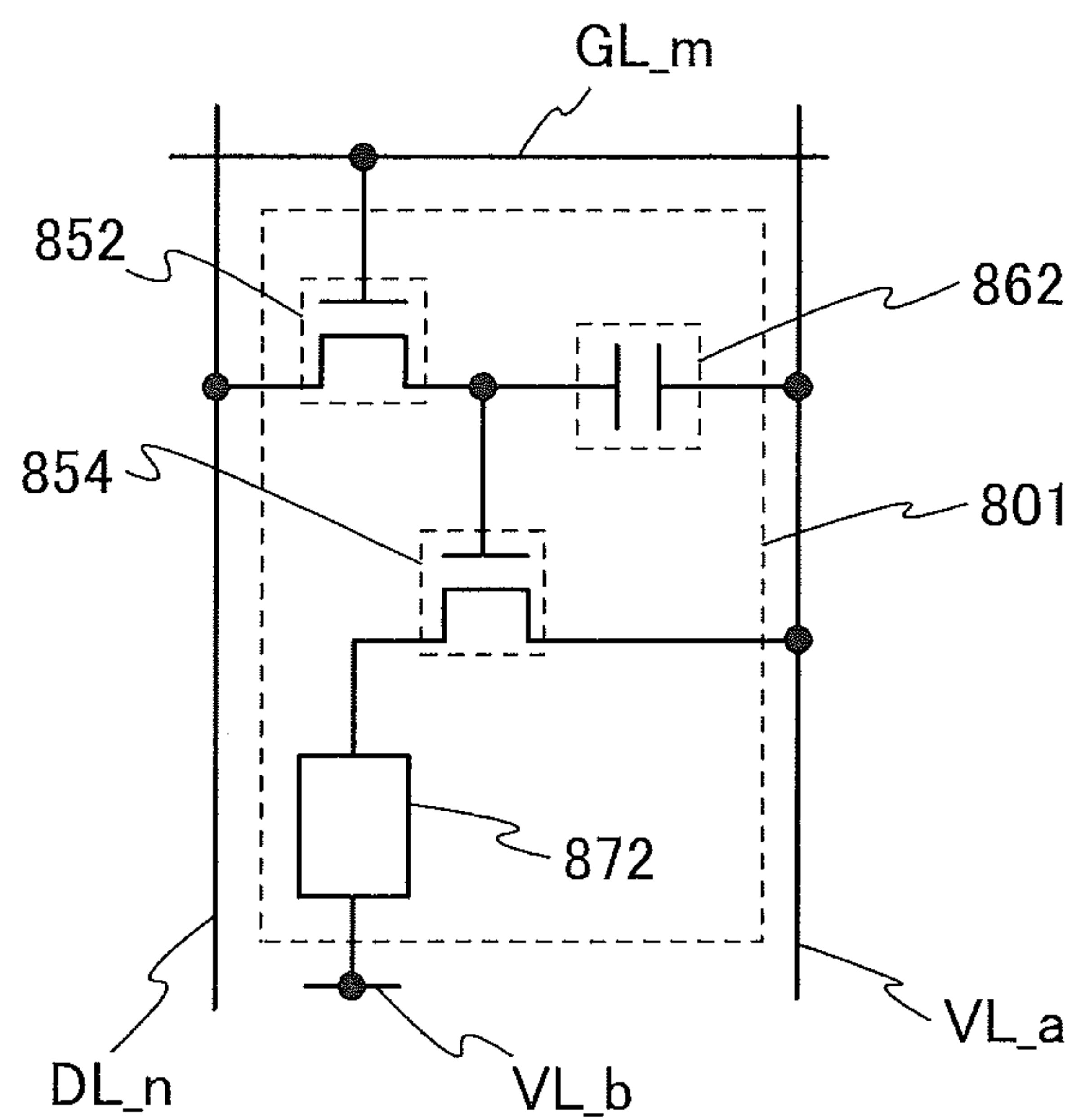


FIG. 19A

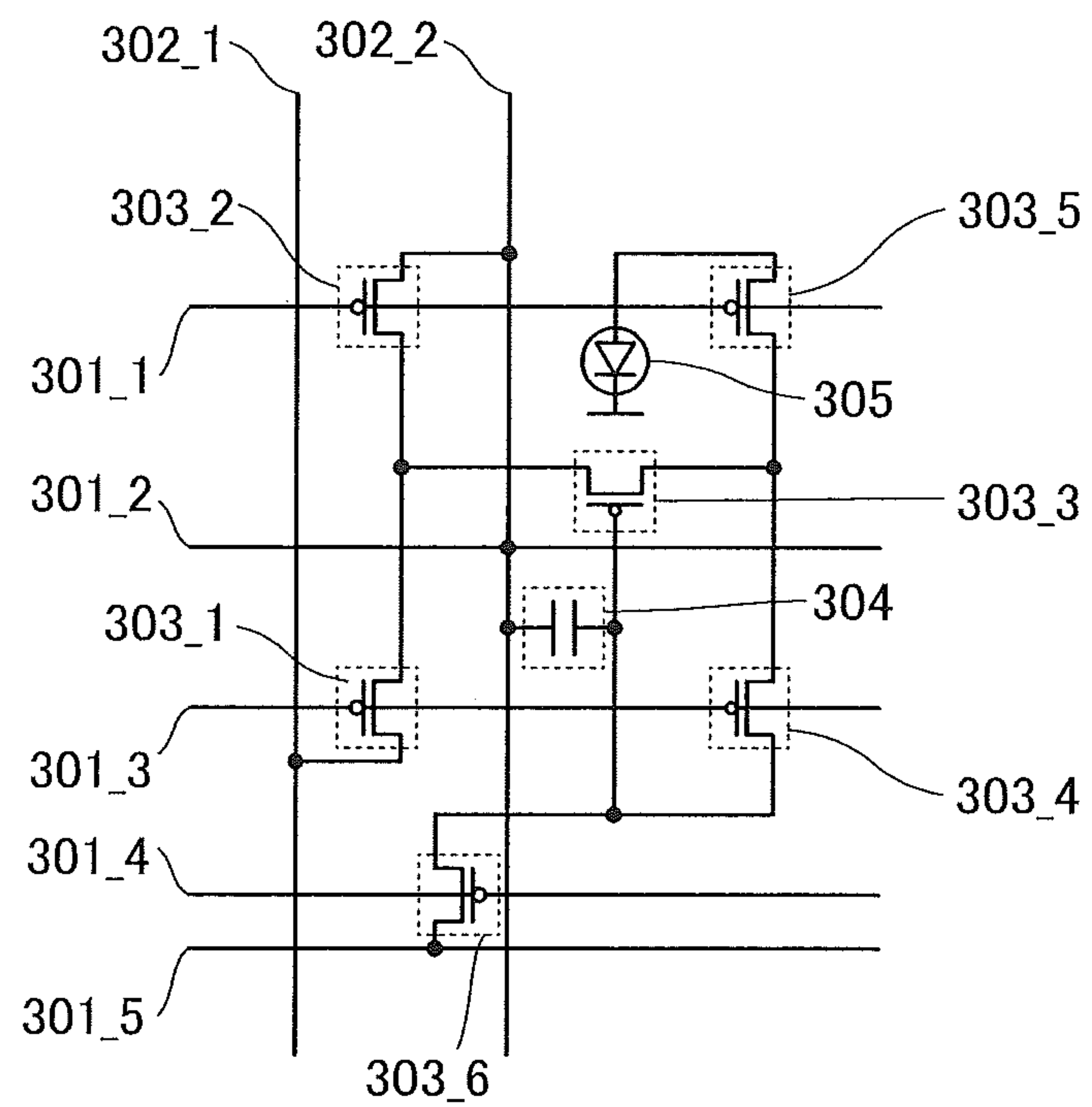


FIG. 19B

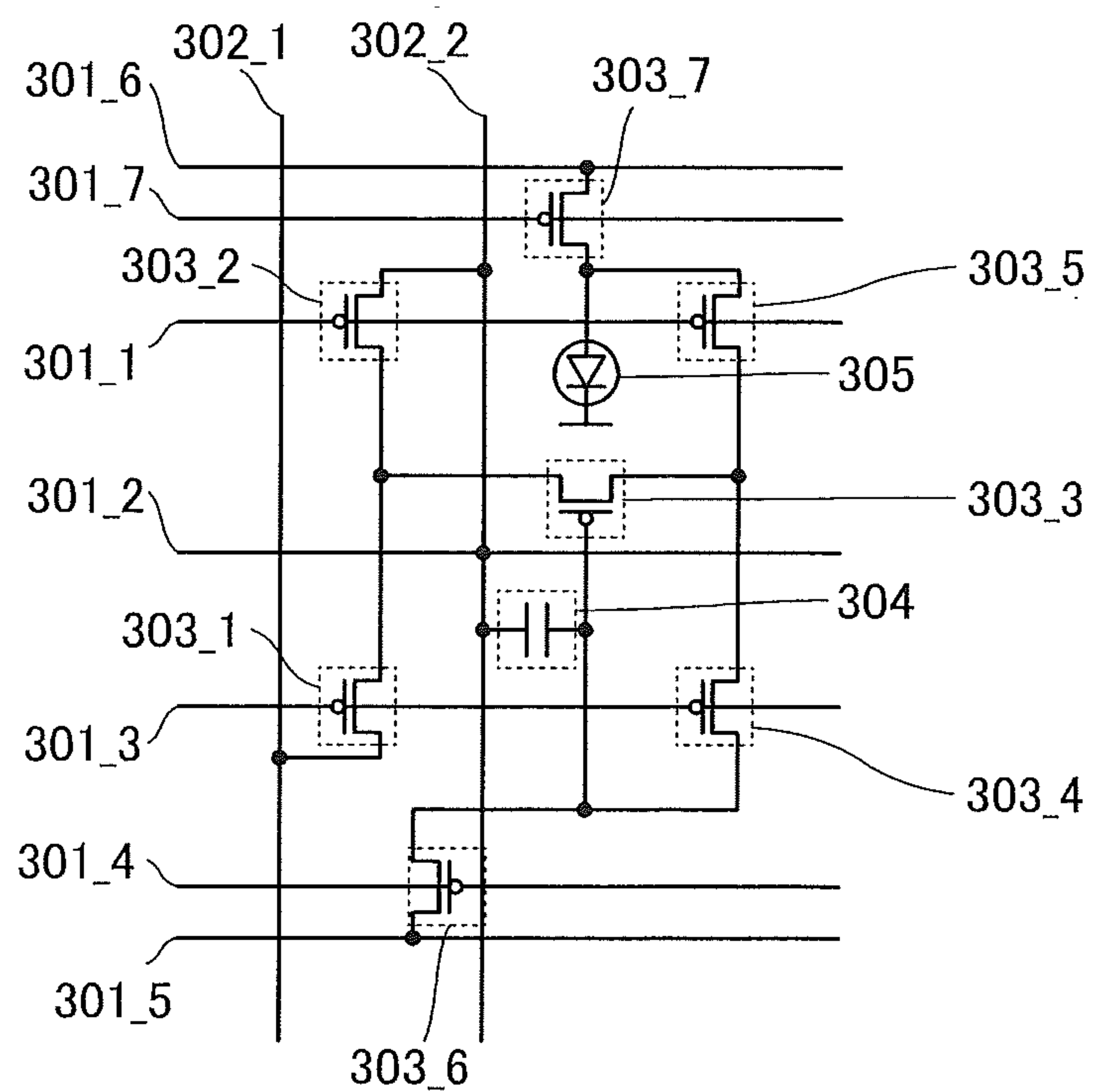


FIG. 20A

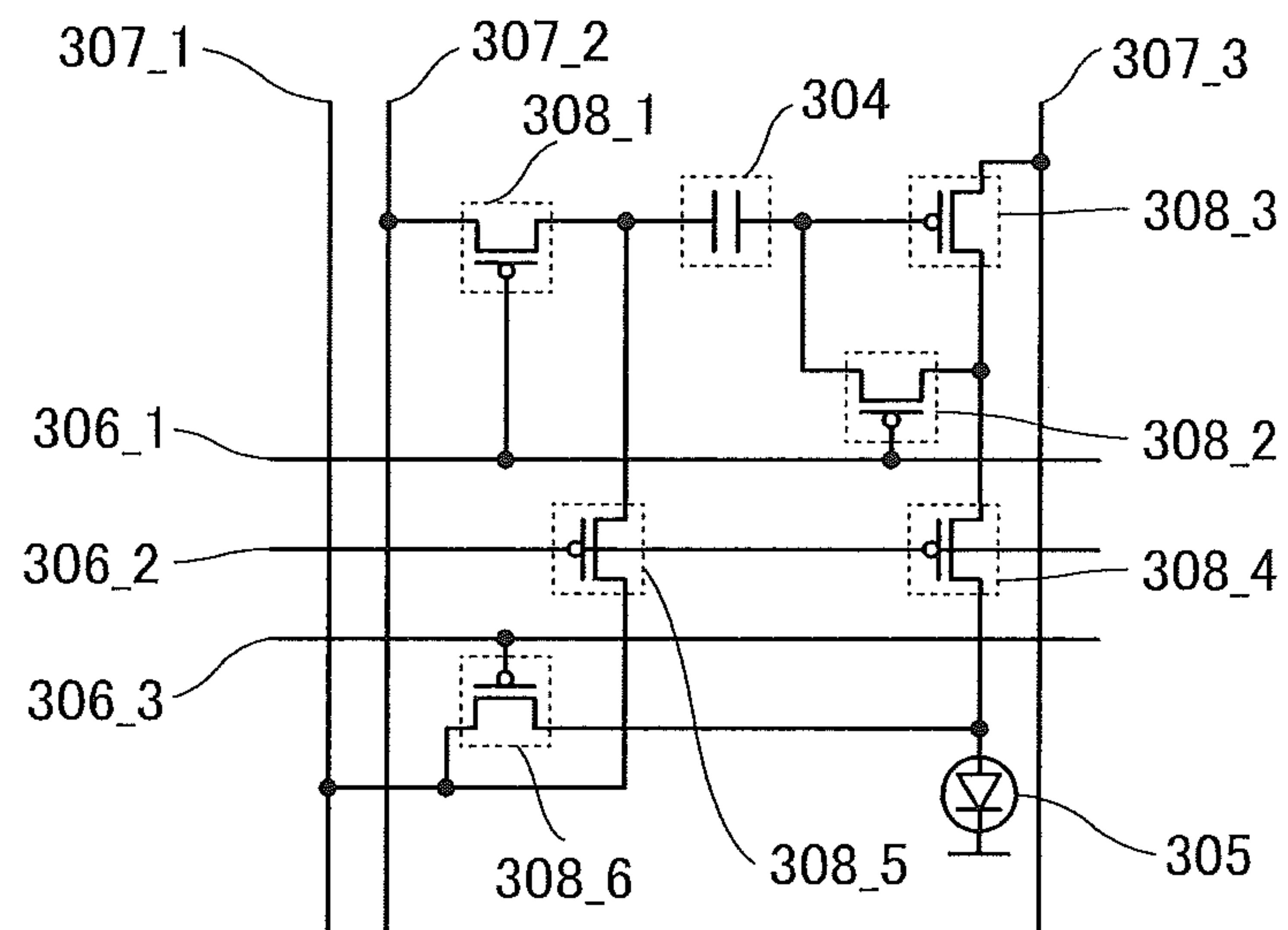


FIG. 20B

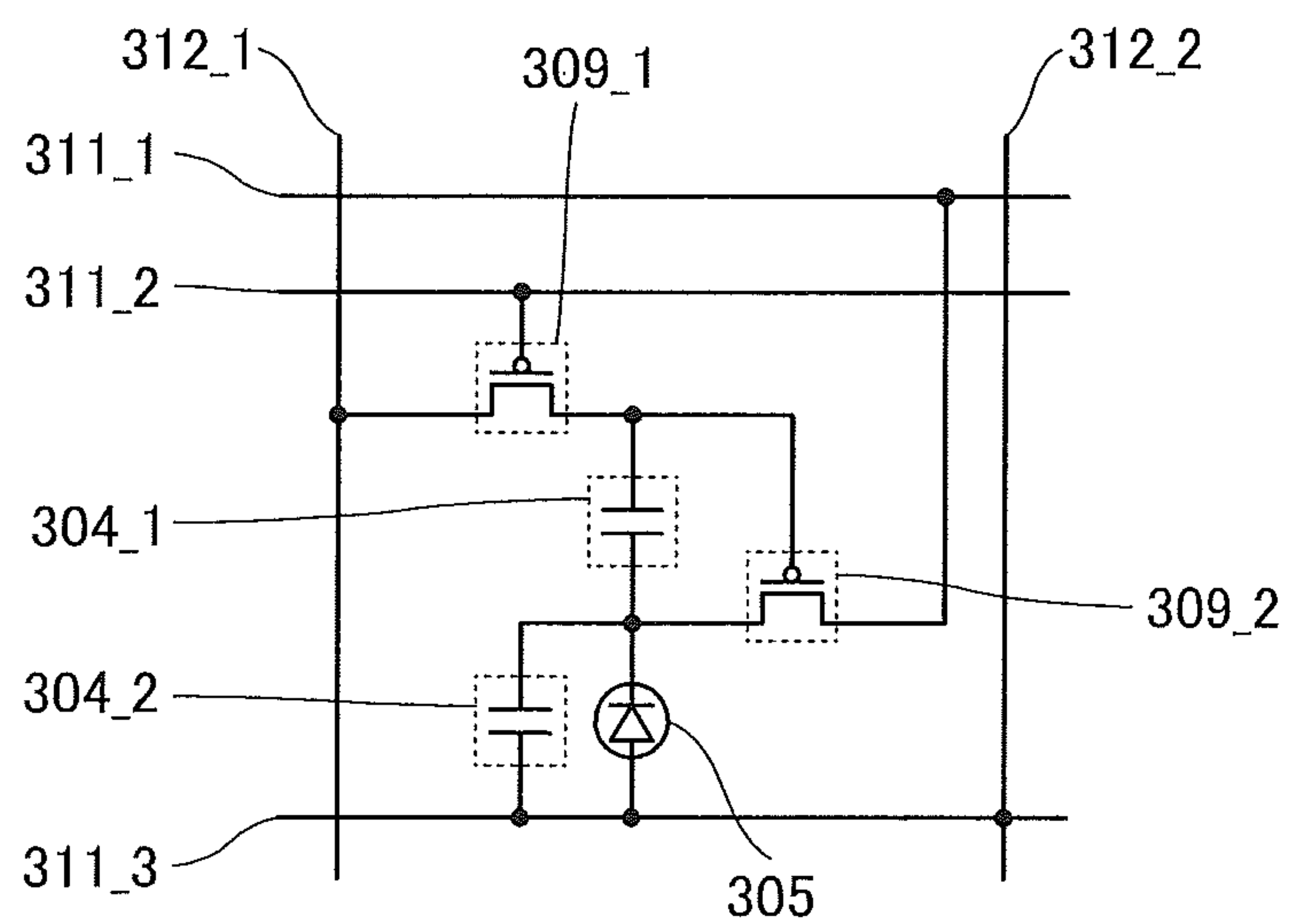


FIG. 21A

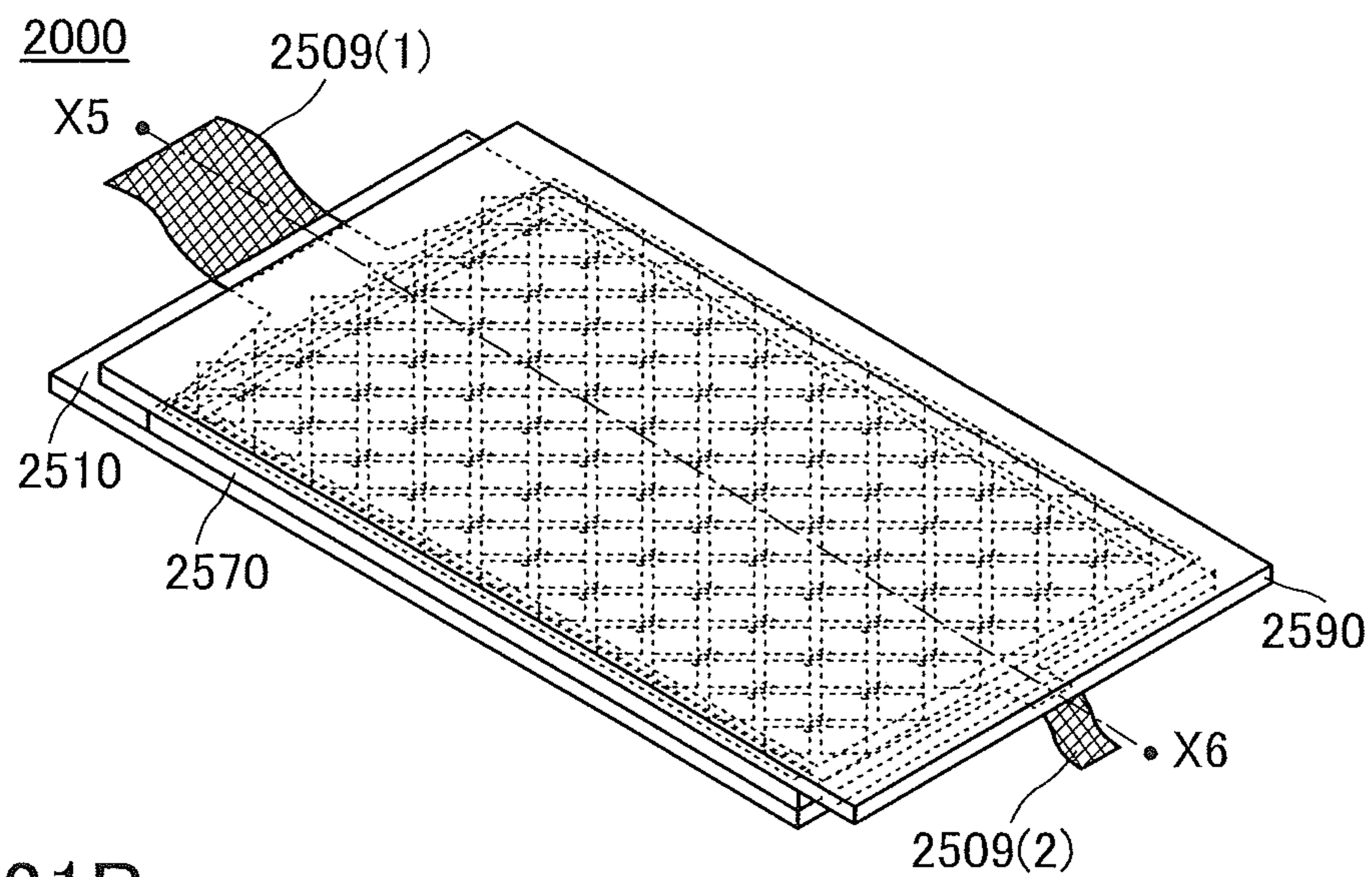


FIG. 21B

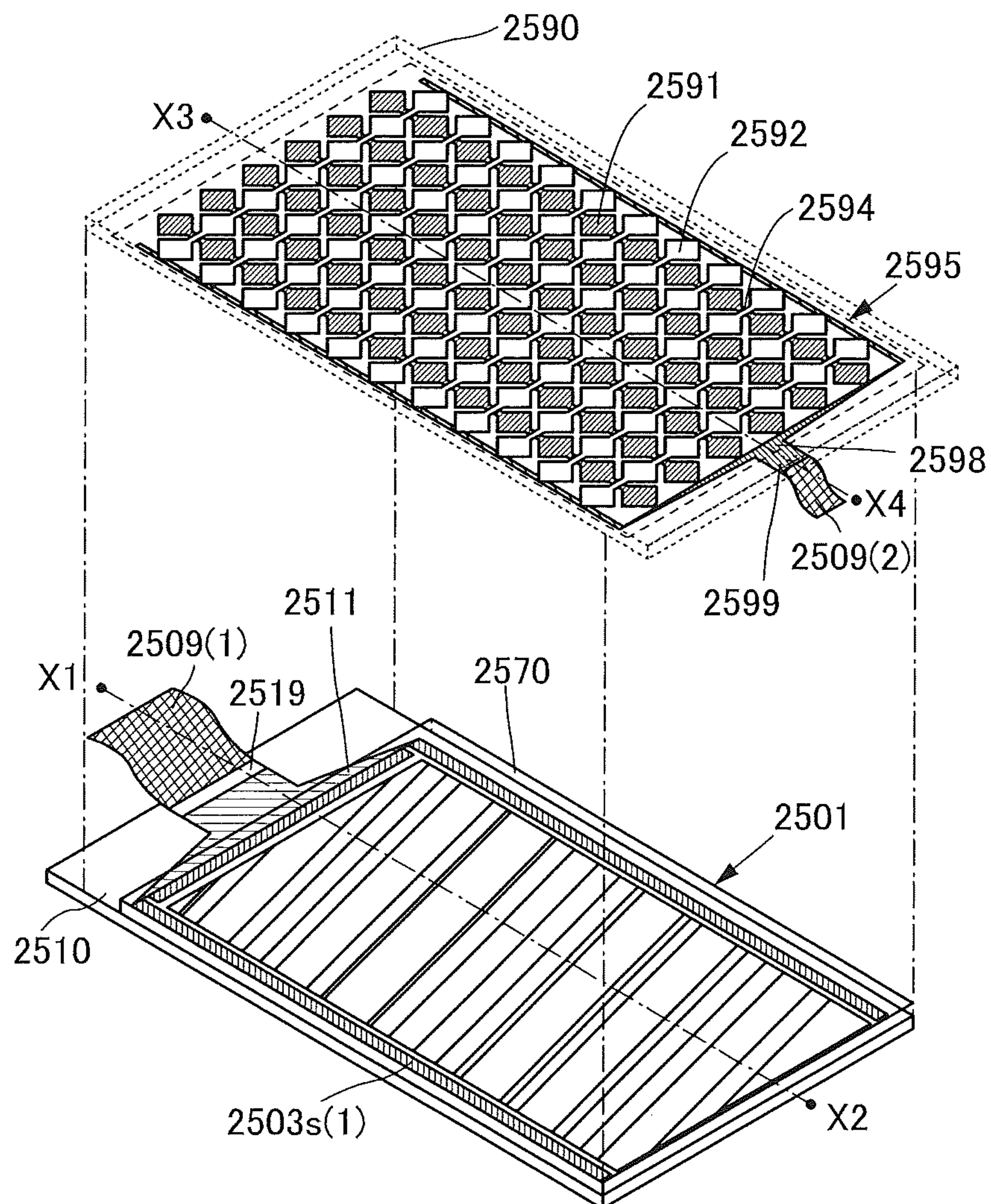


FIG. 22A

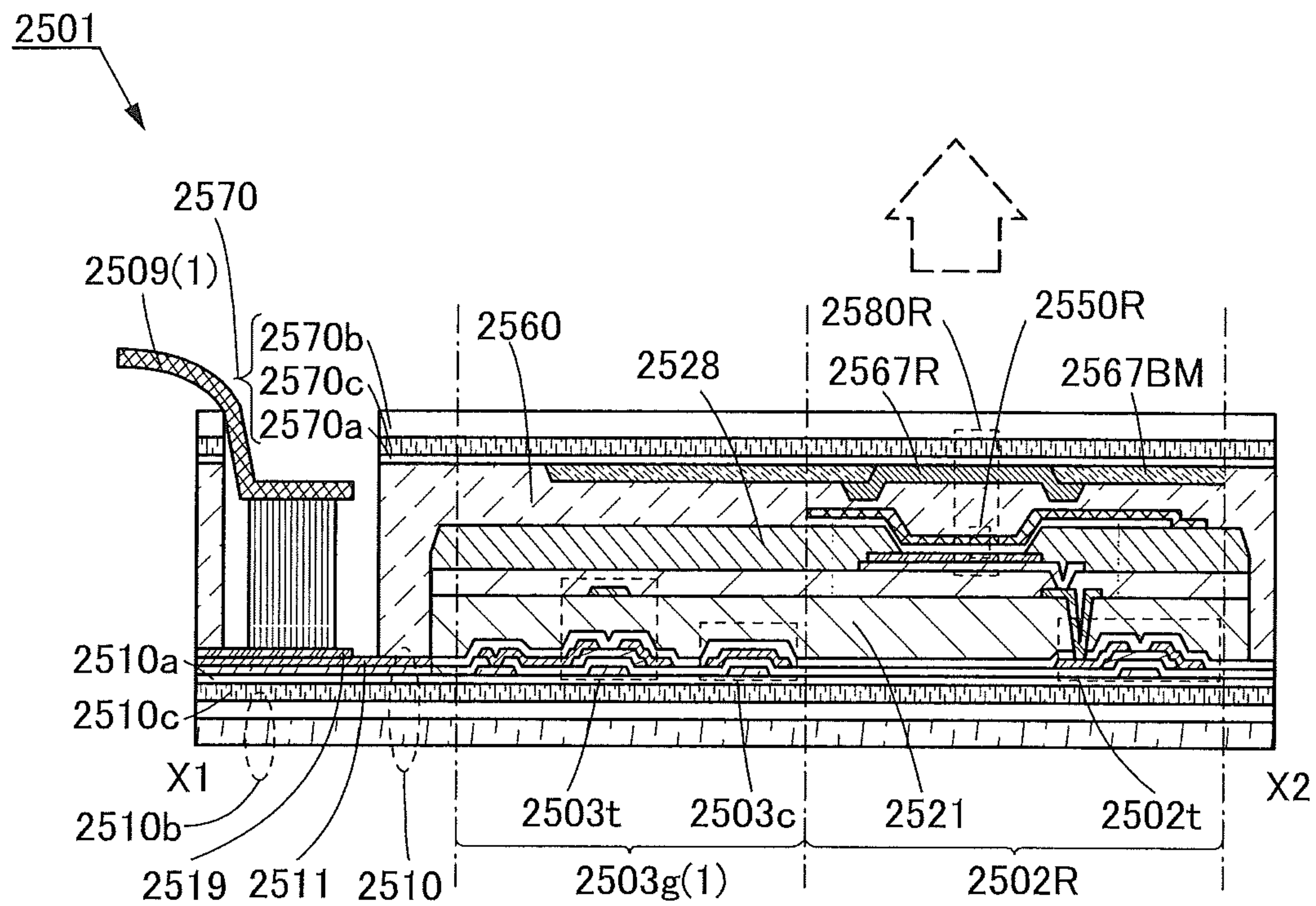


FIG. 22B

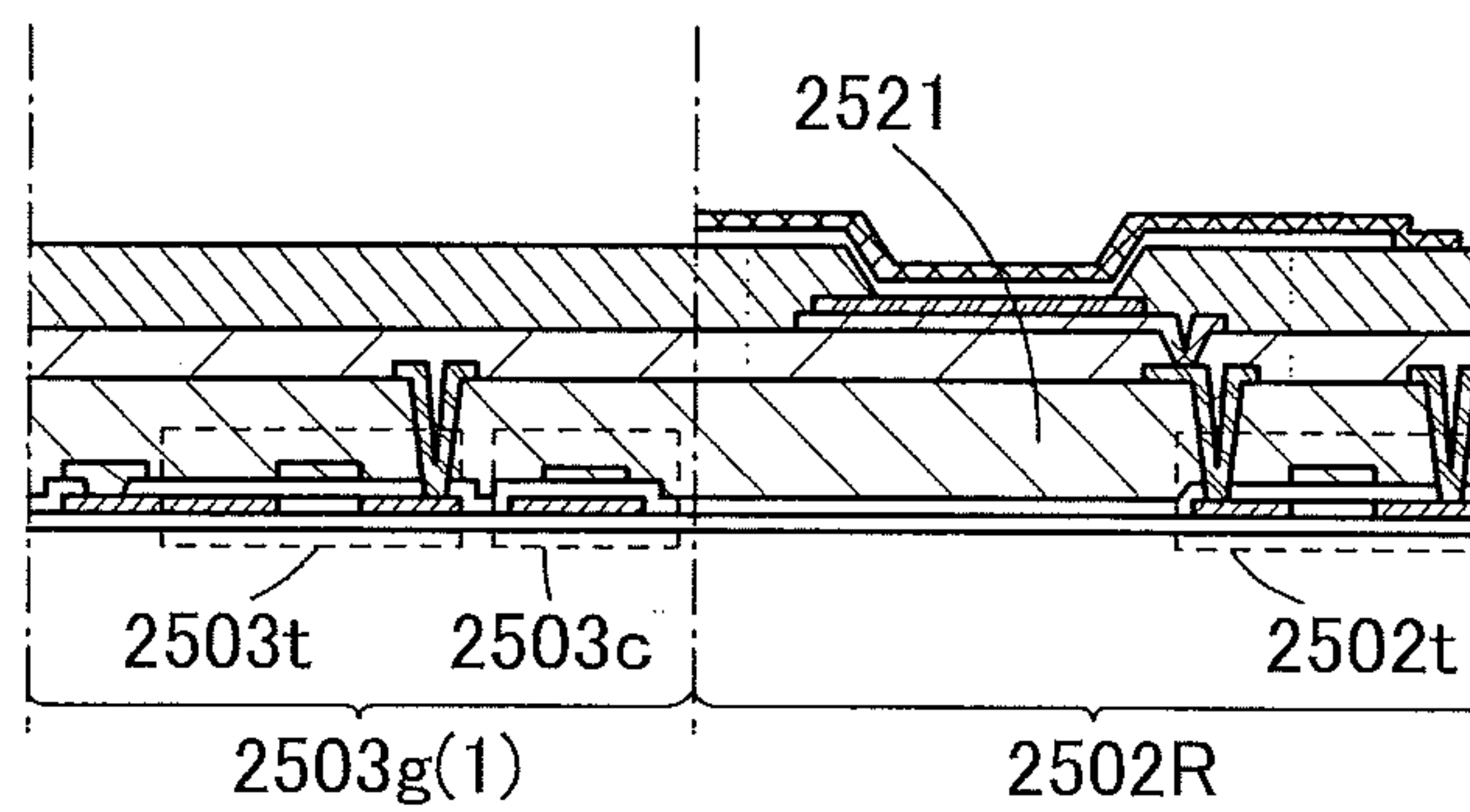


FIG. 22C

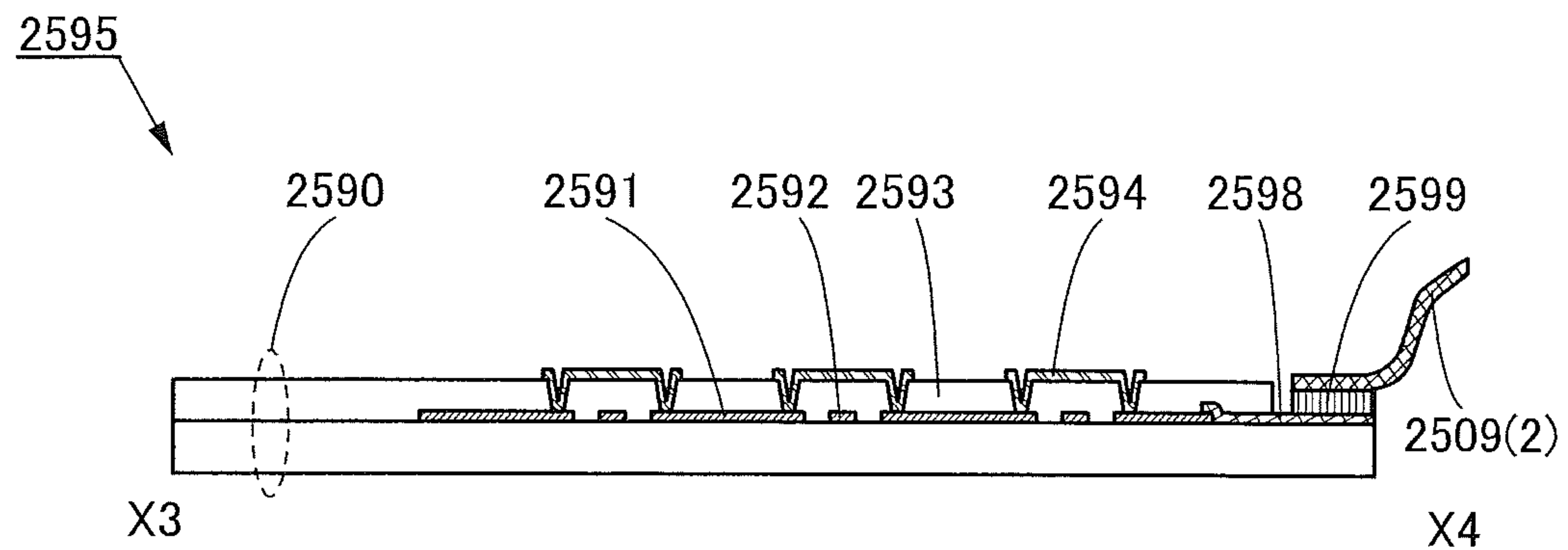


FIG. 23A

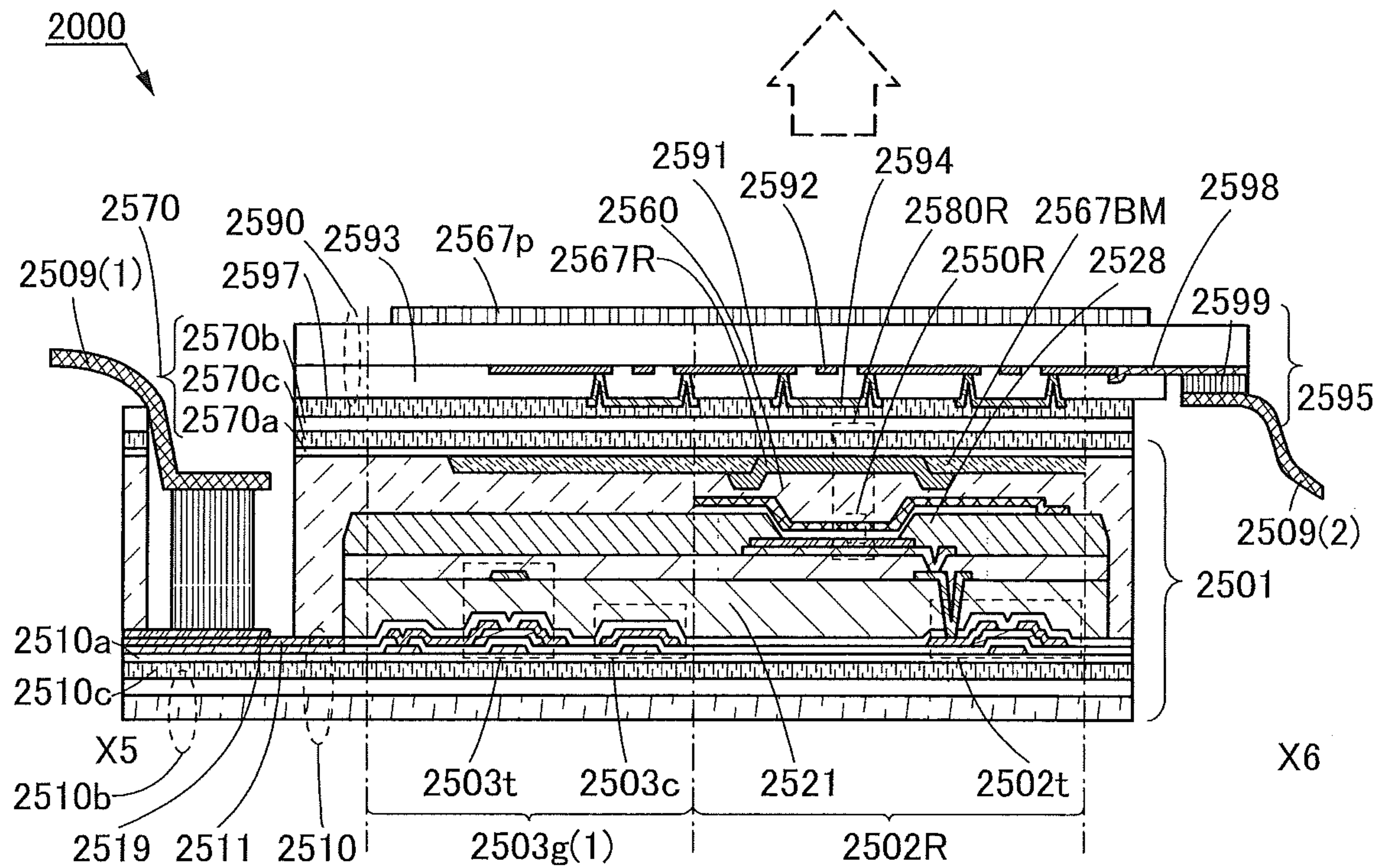


FIG. 23B

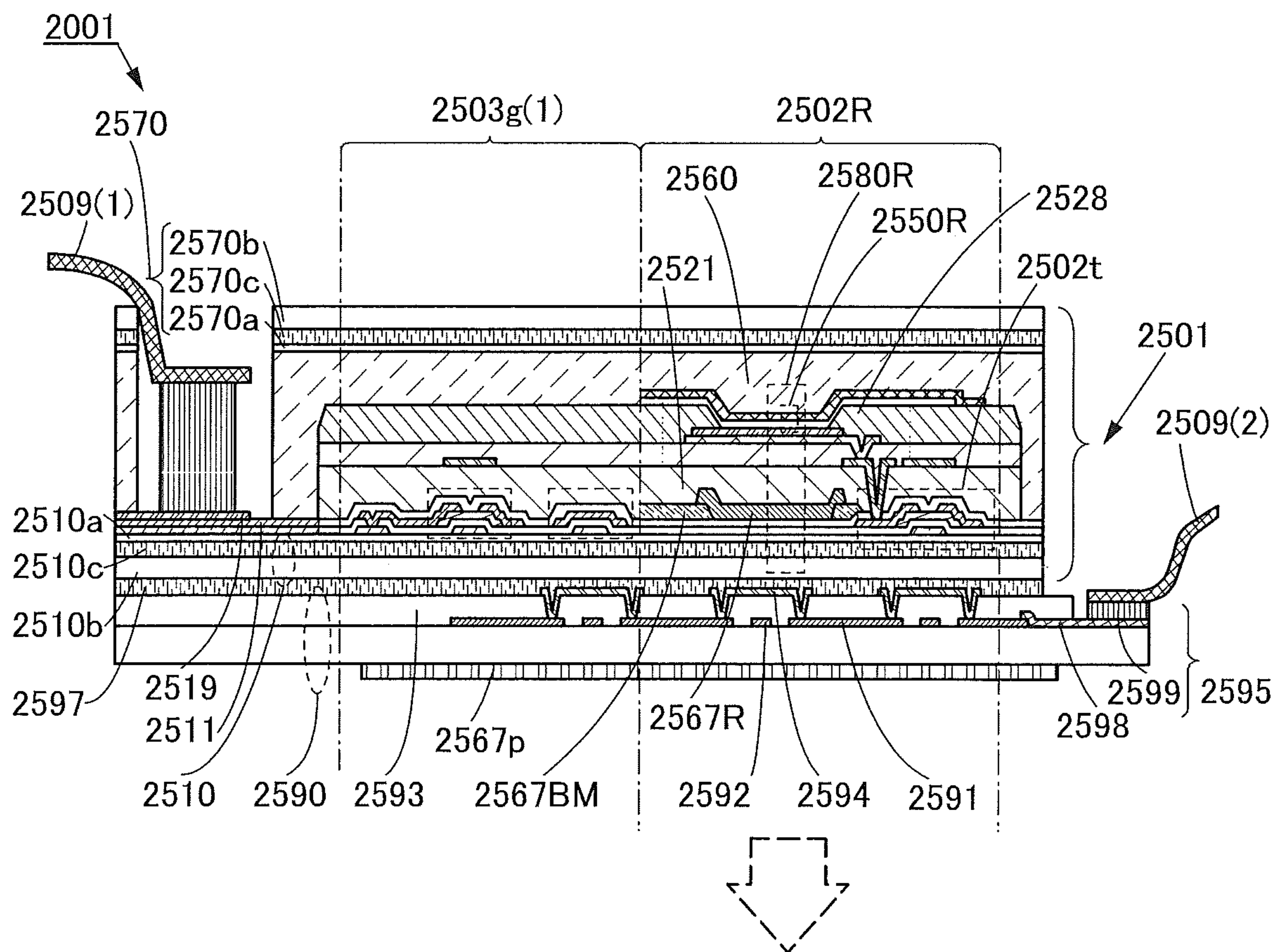


FIG. 24A

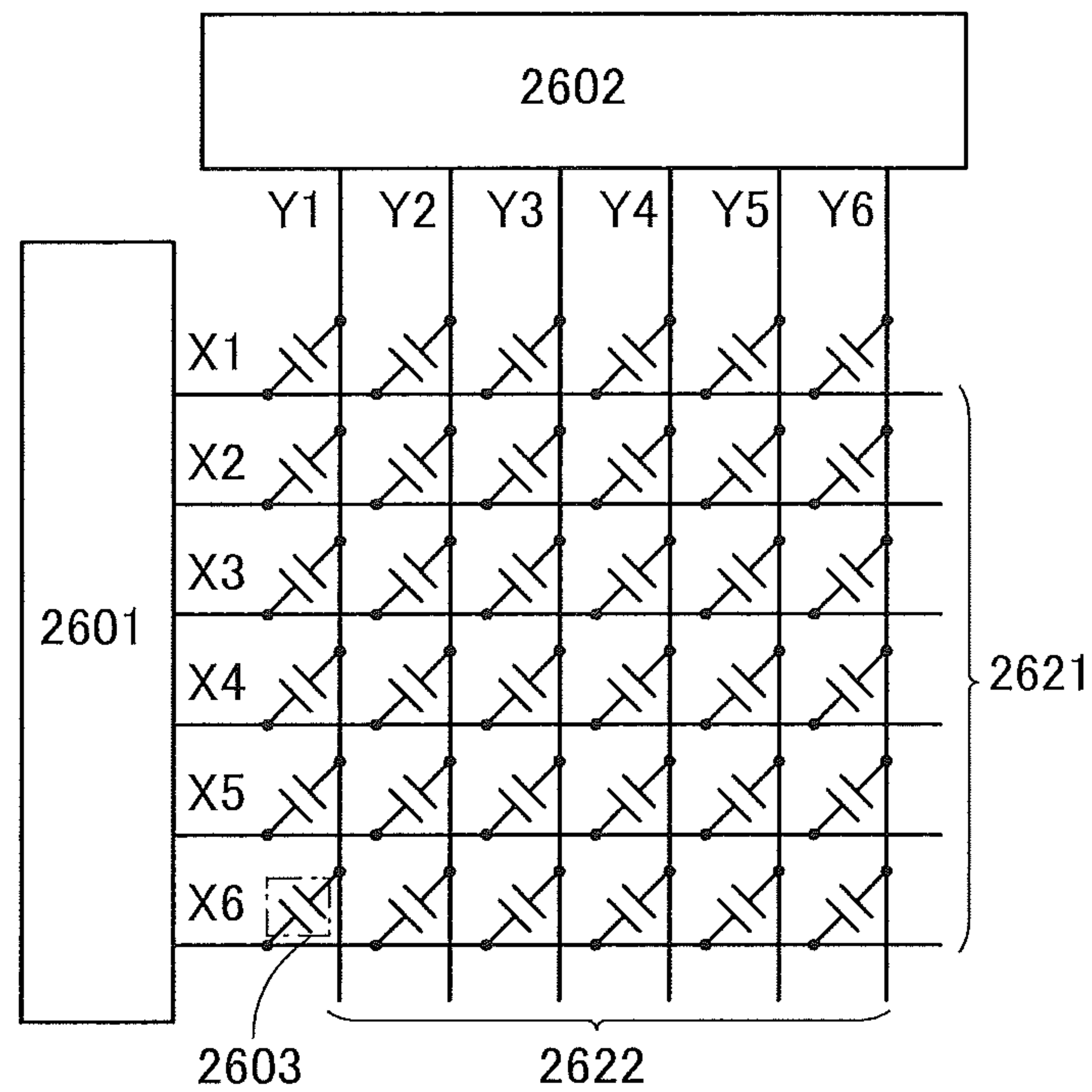


FIG. 24B

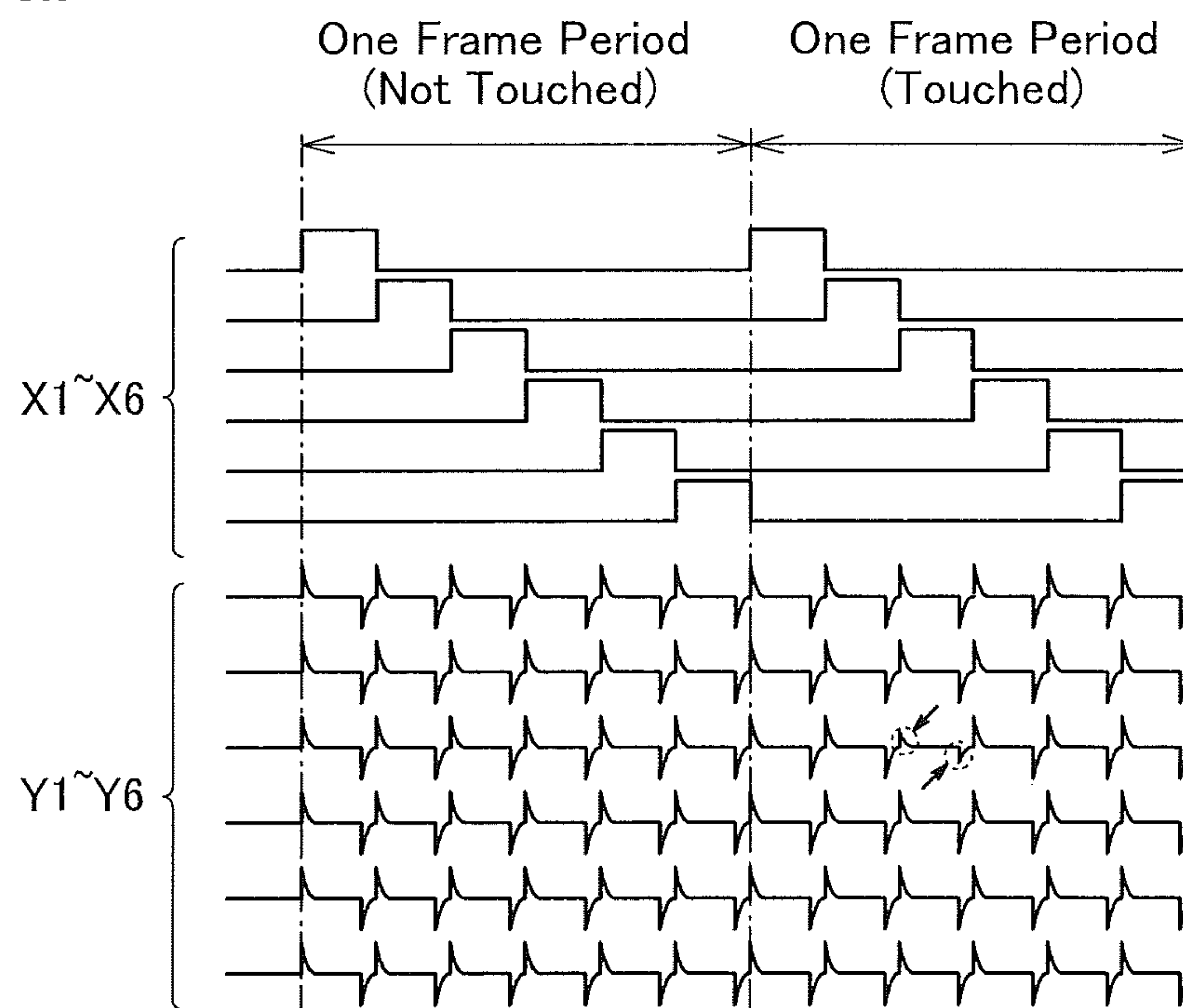


FIG. 25

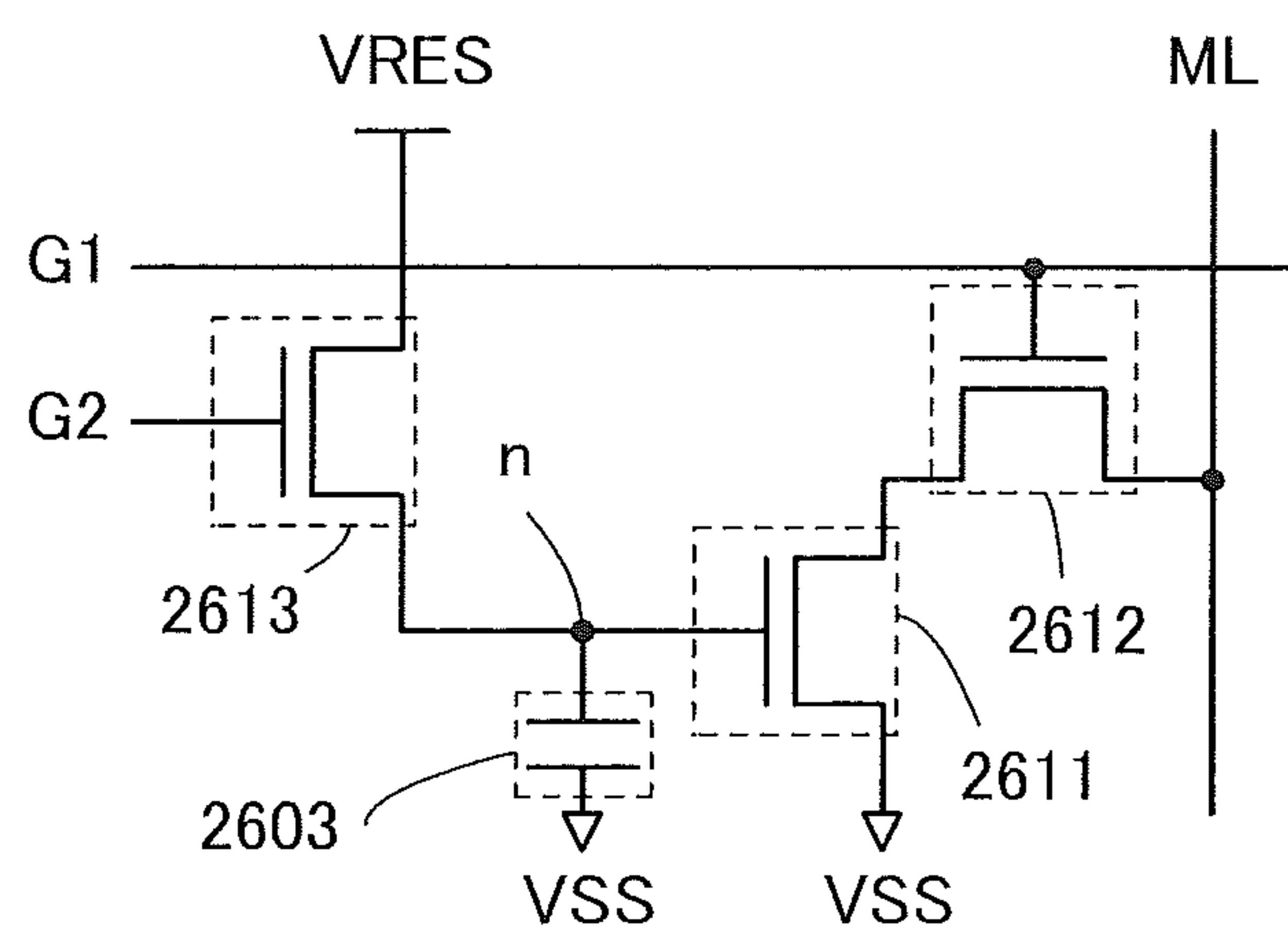


FIG. 26

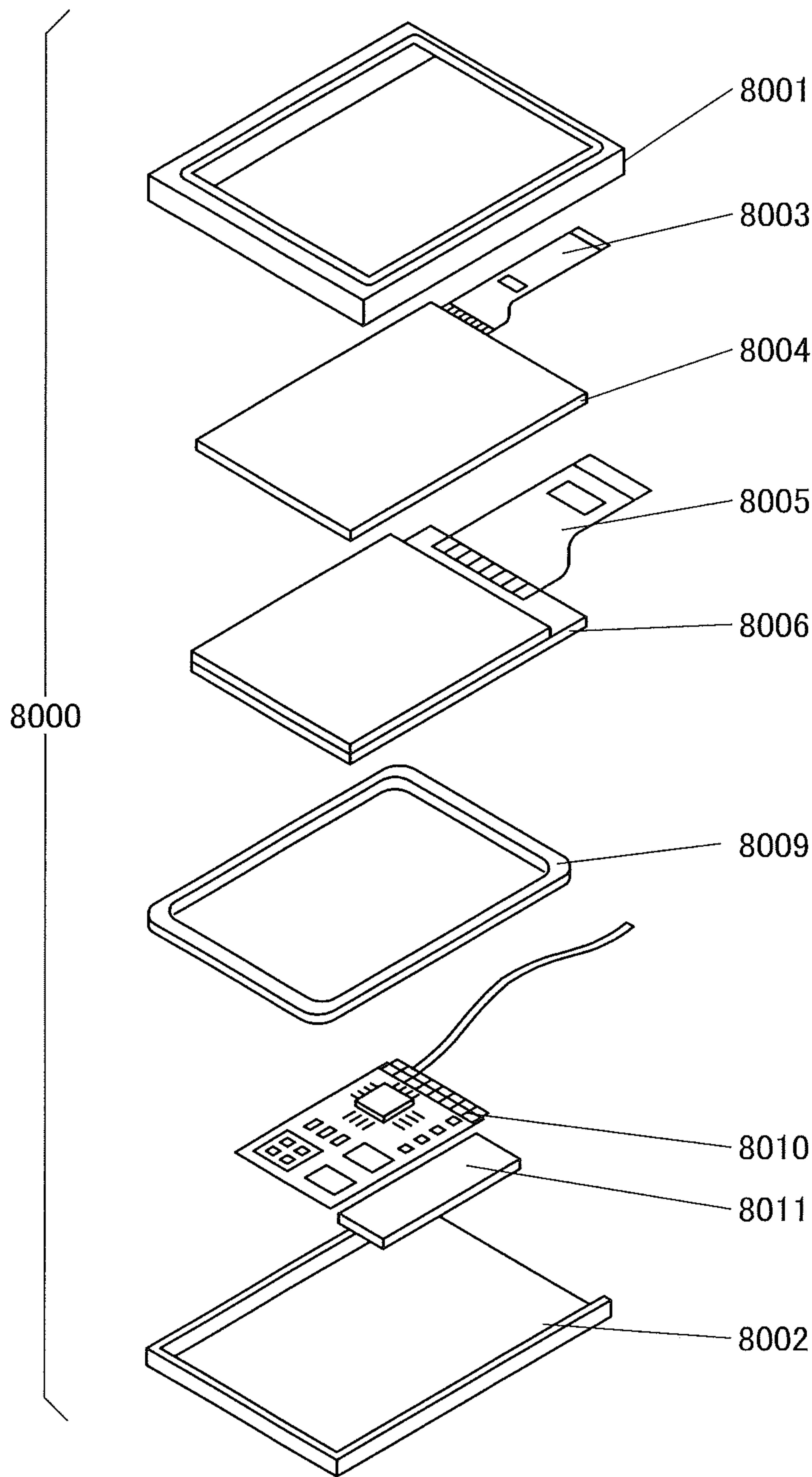


FIG. 27A

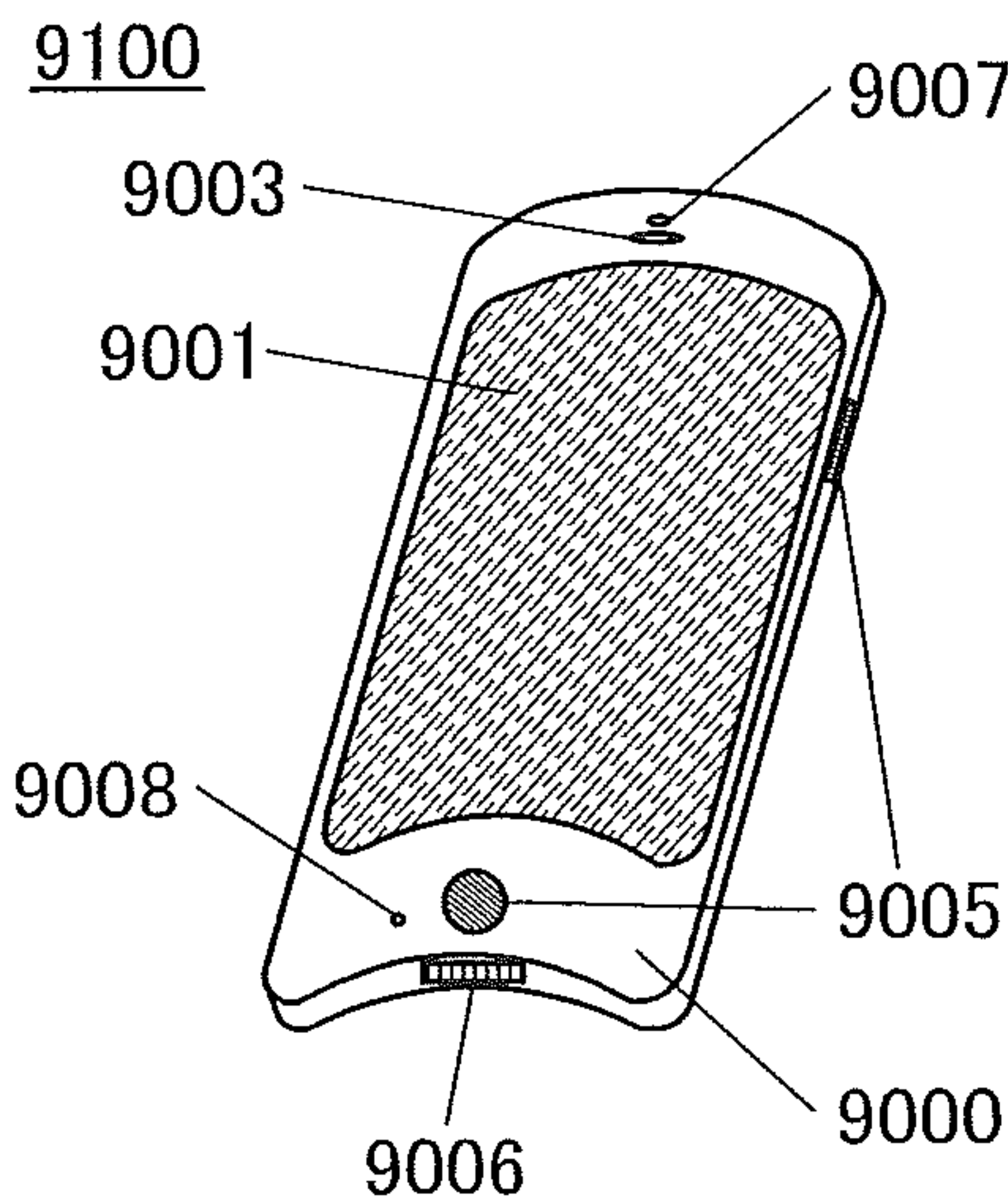


FIG. 27D

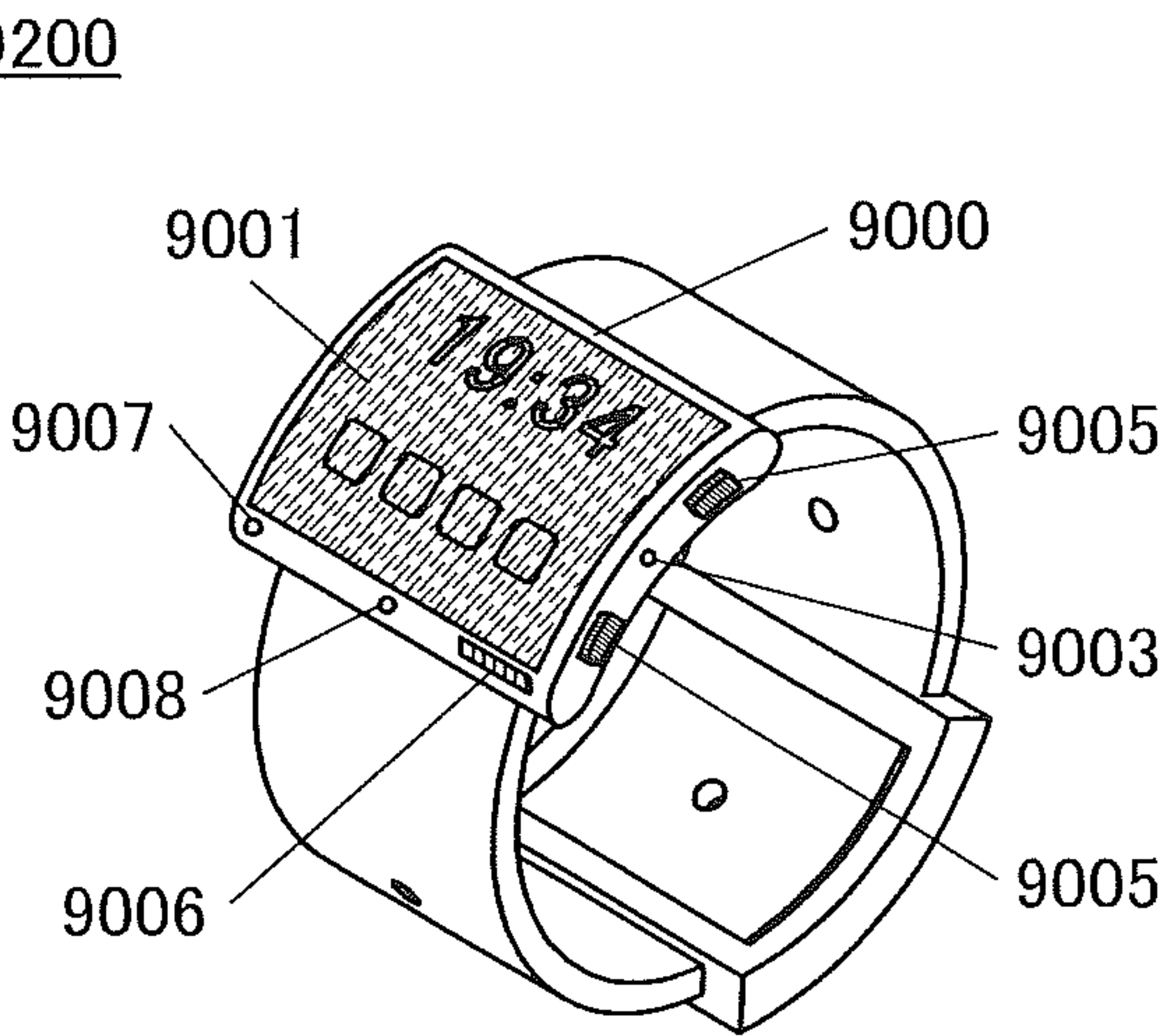


FIG. 27B

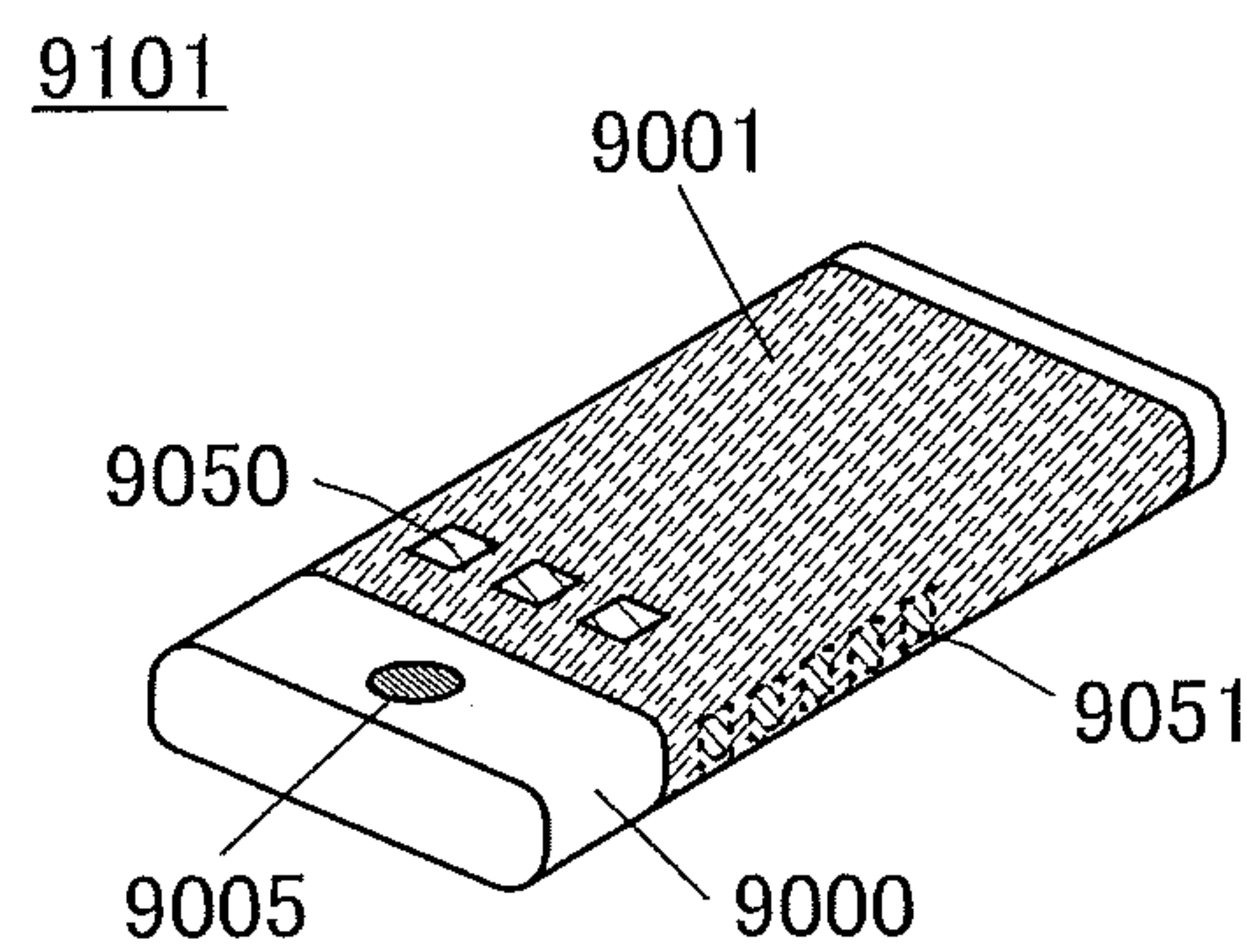


FIG. 27E

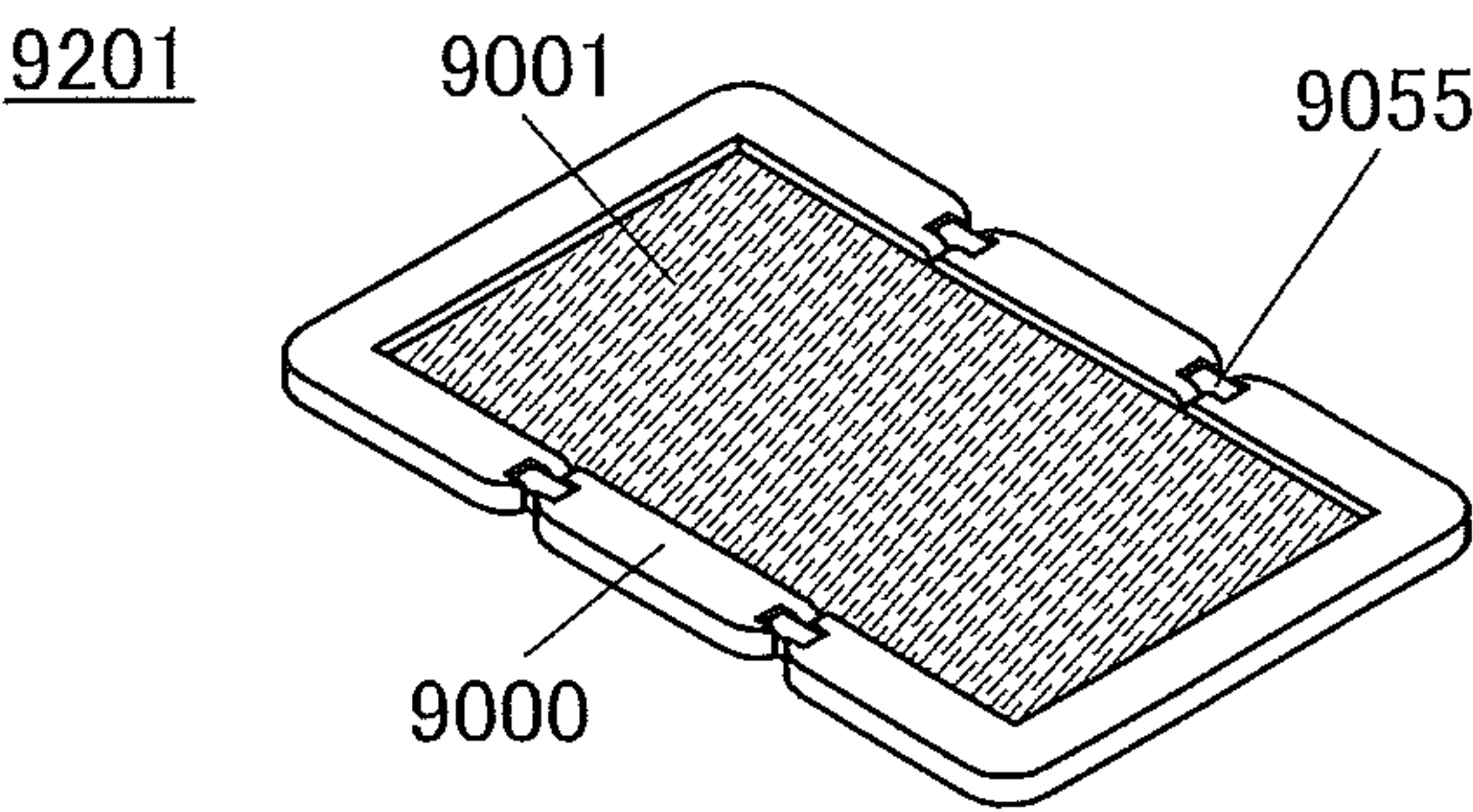


FIG. 27C

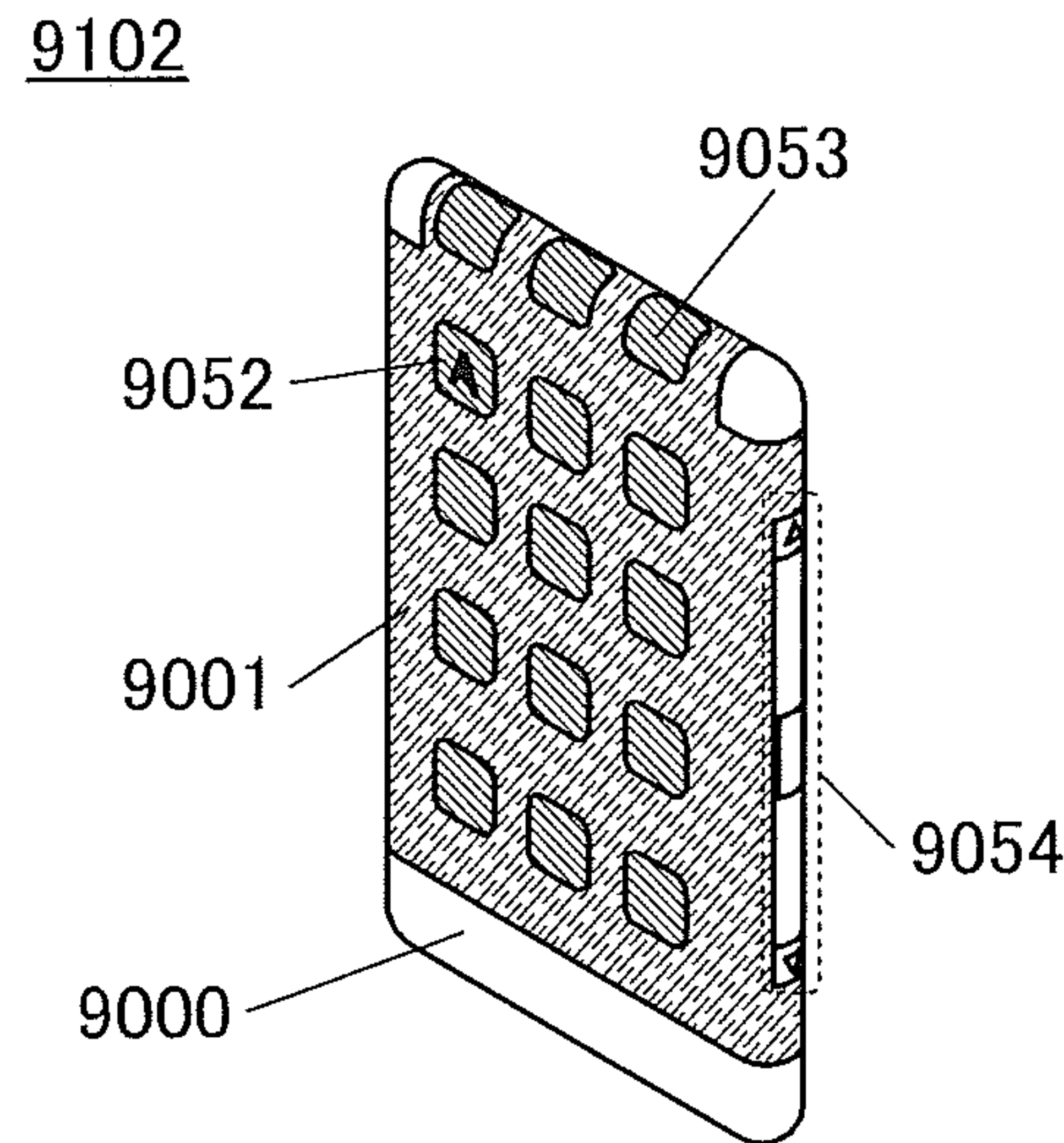


FIG. 27F

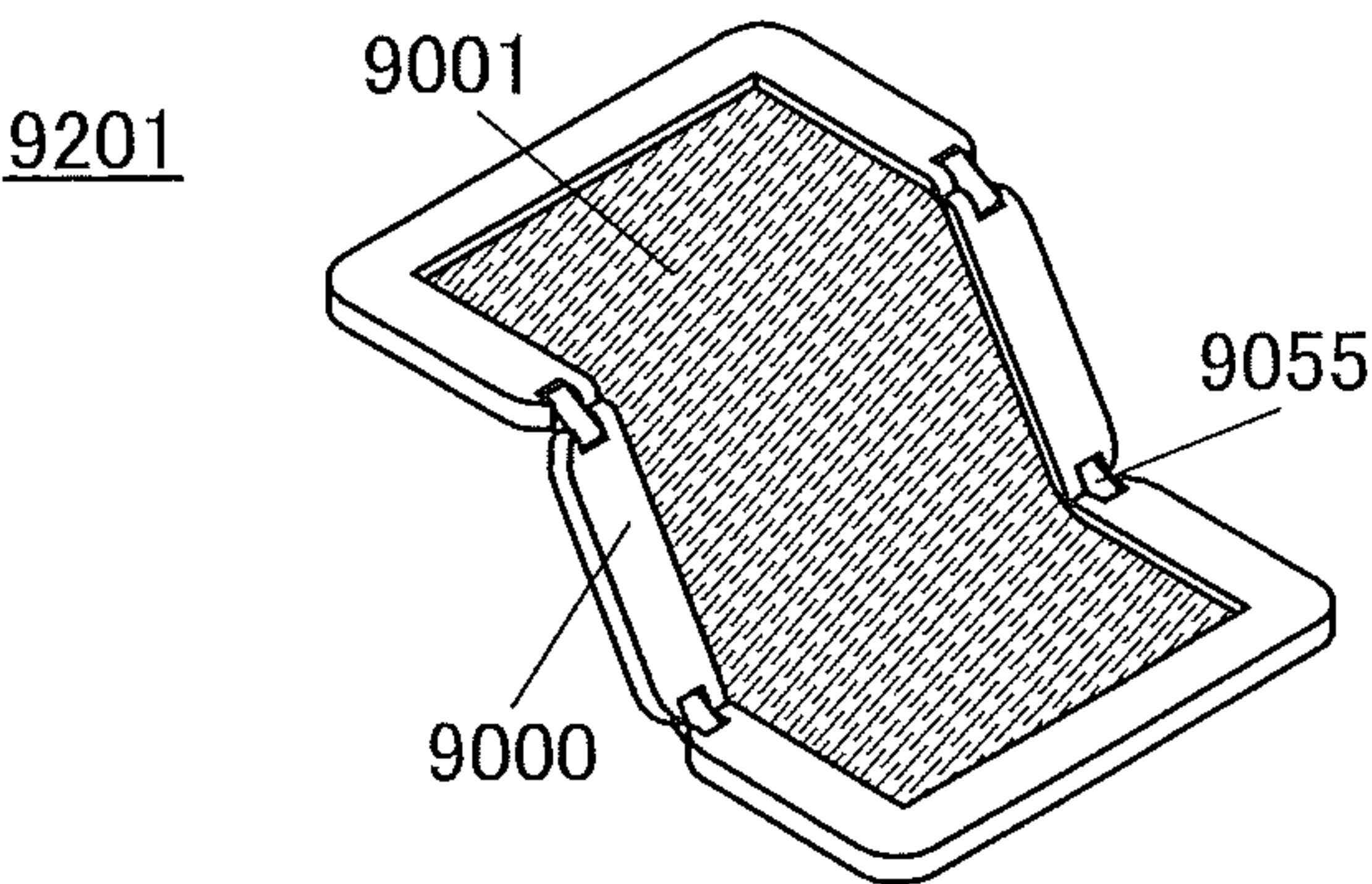


FIG. 27G

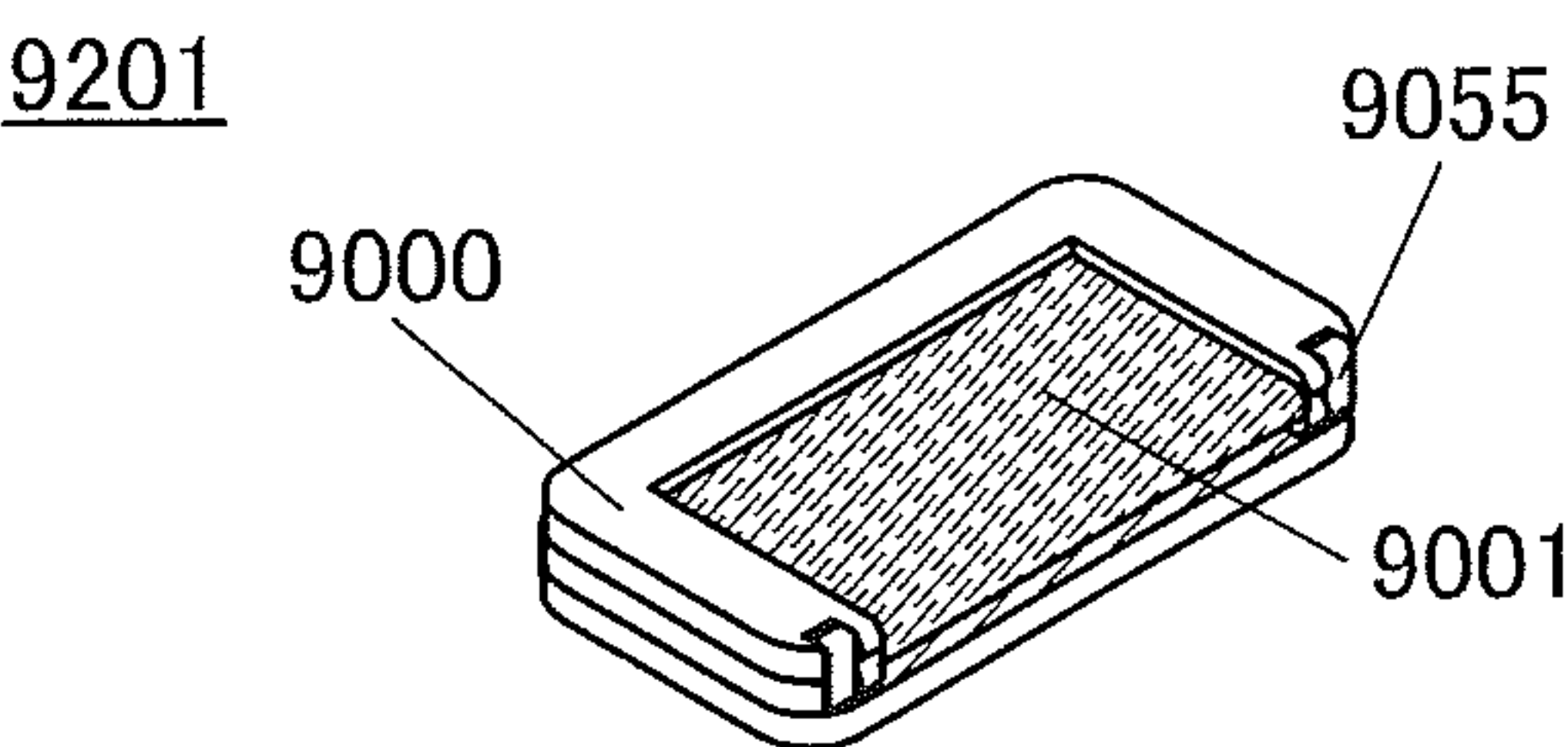


FIG. 28A

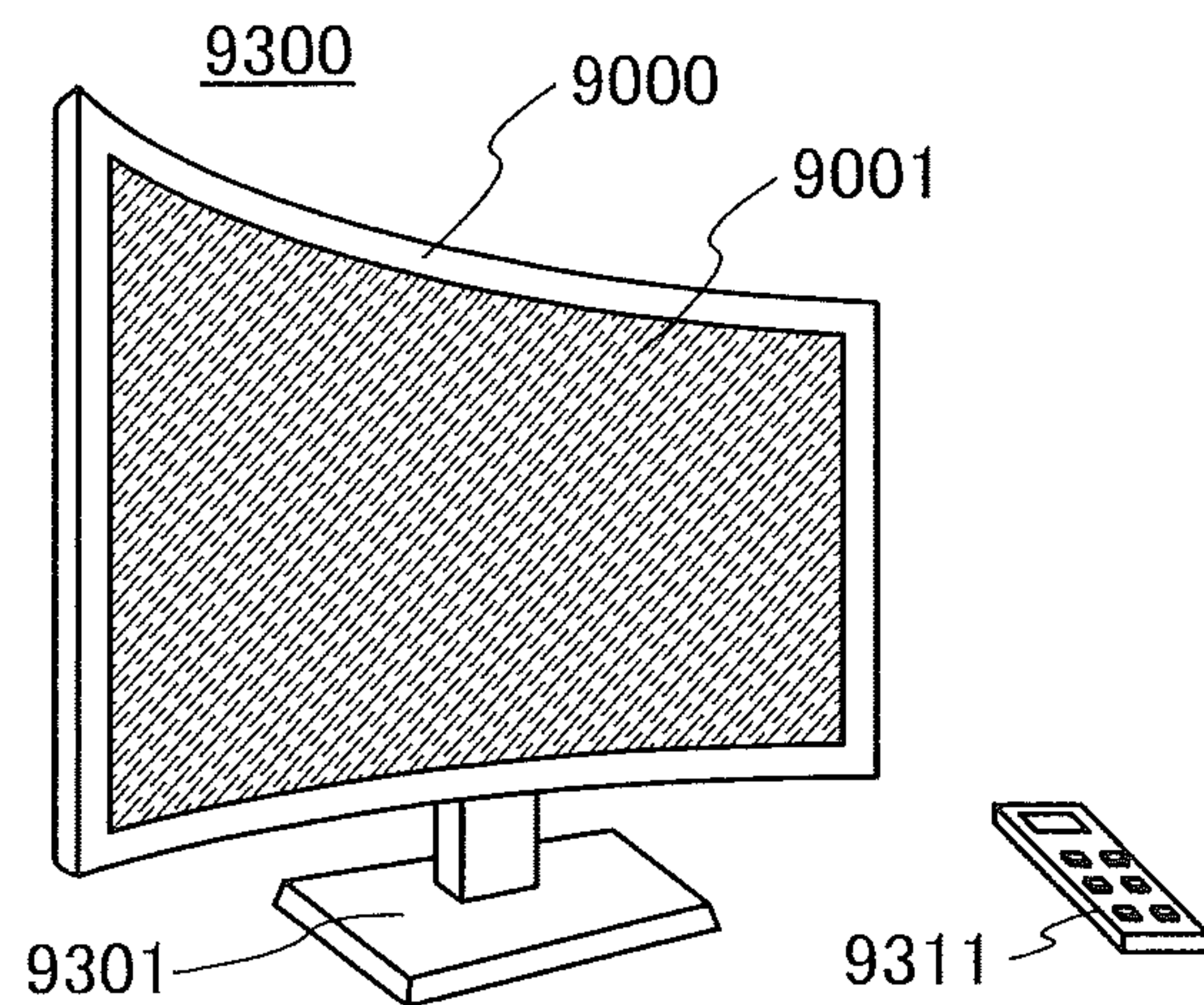


FIG. 28B

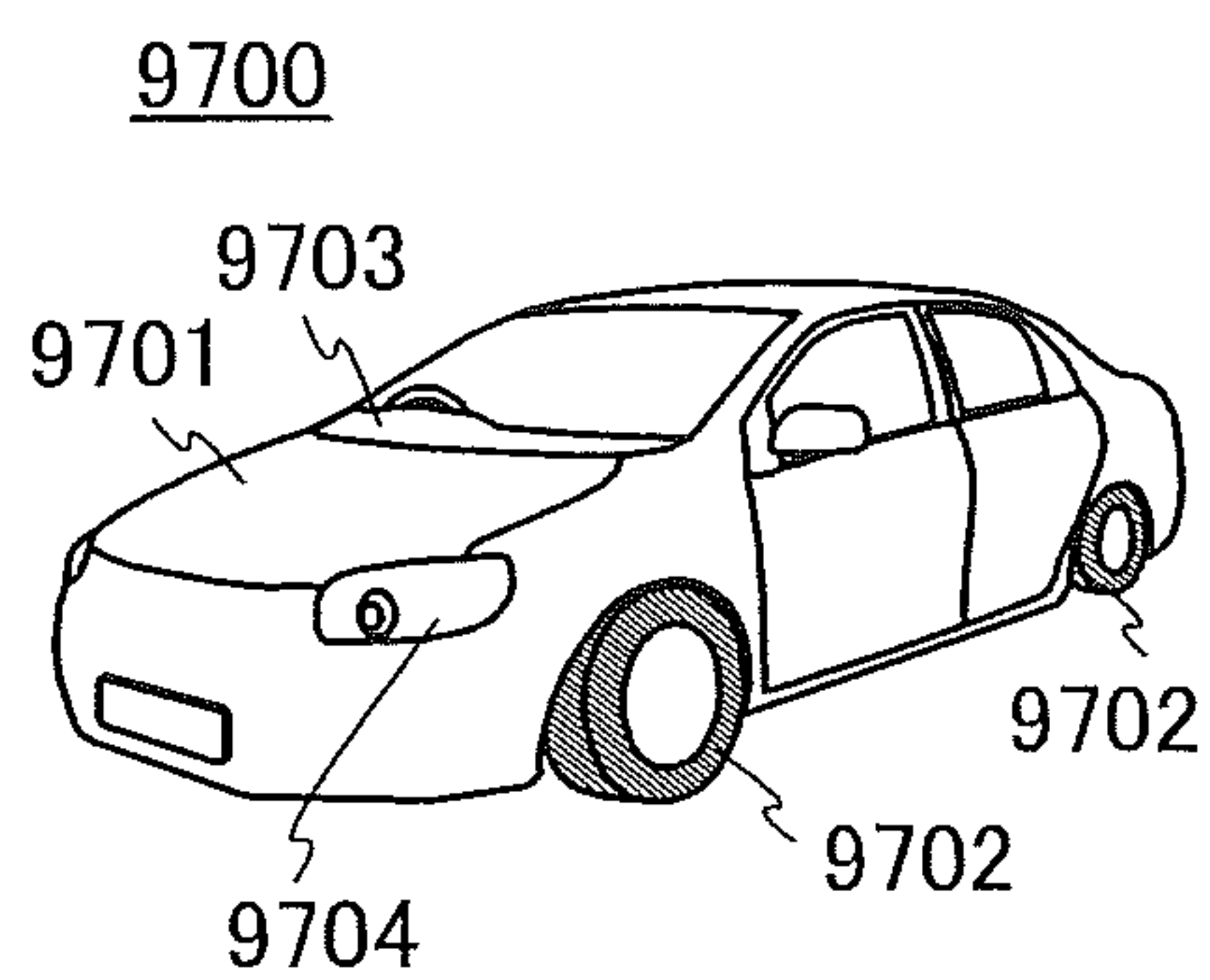


FIG. 28C

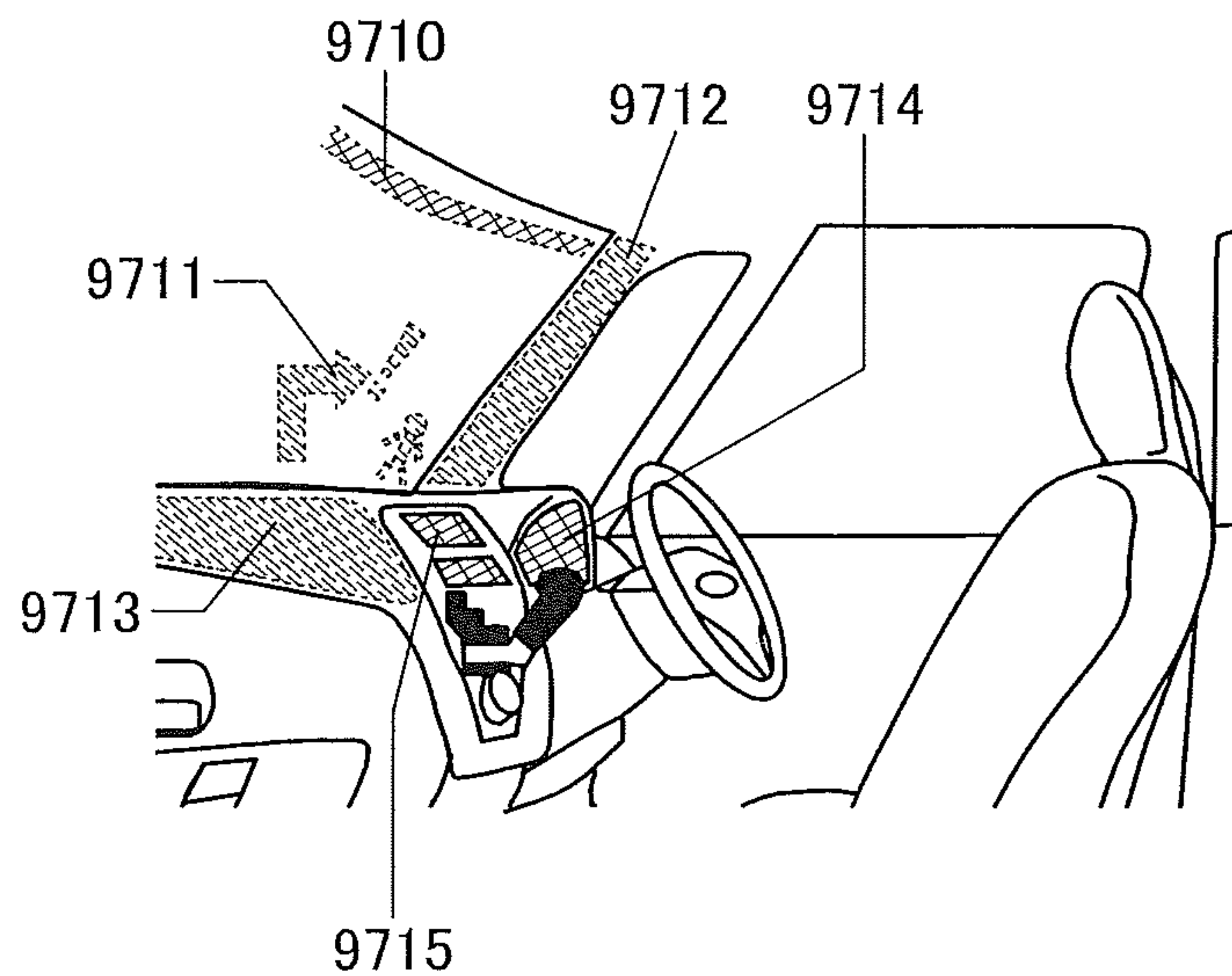


FIG. 28D

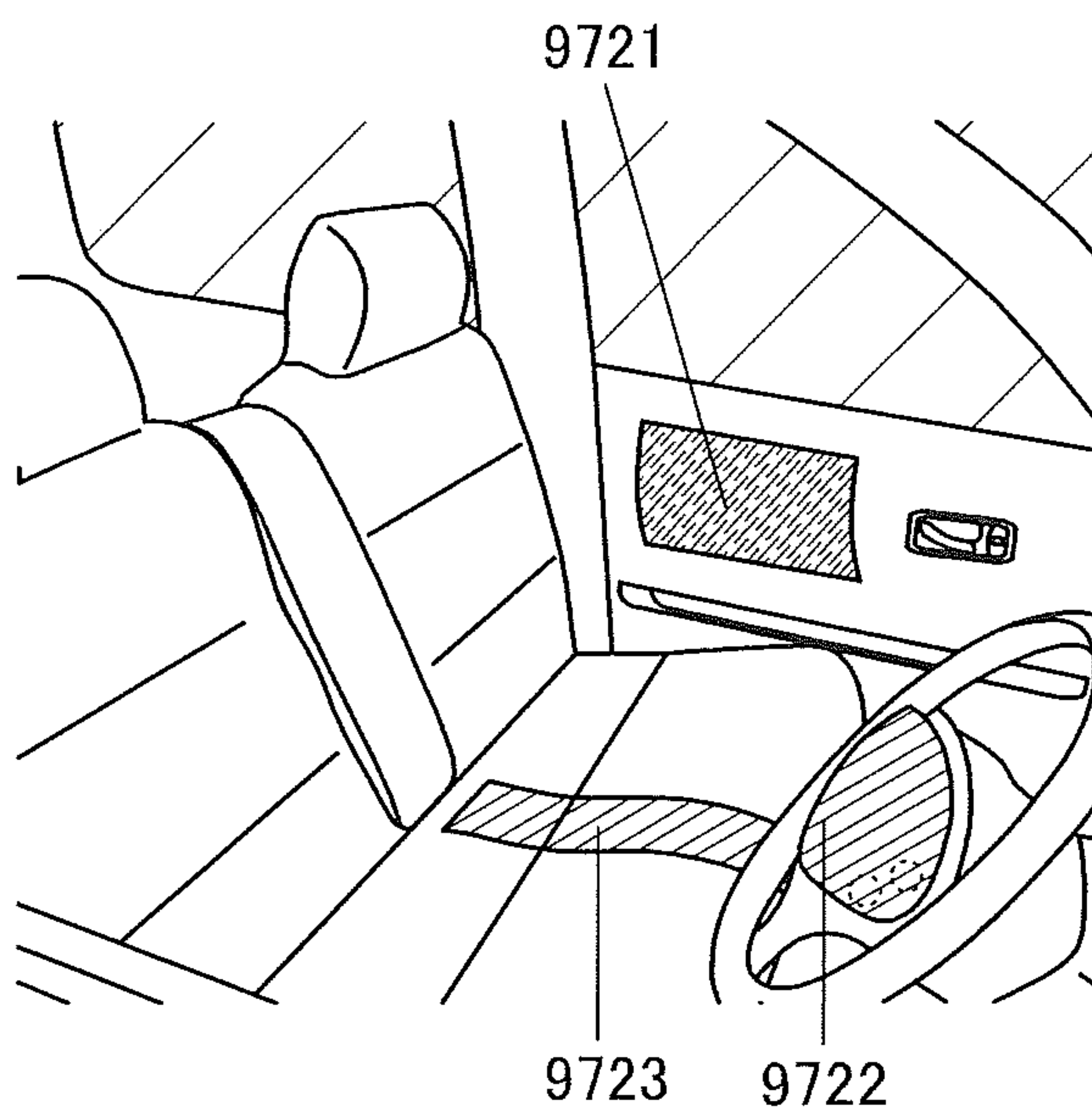


FIG. 29A

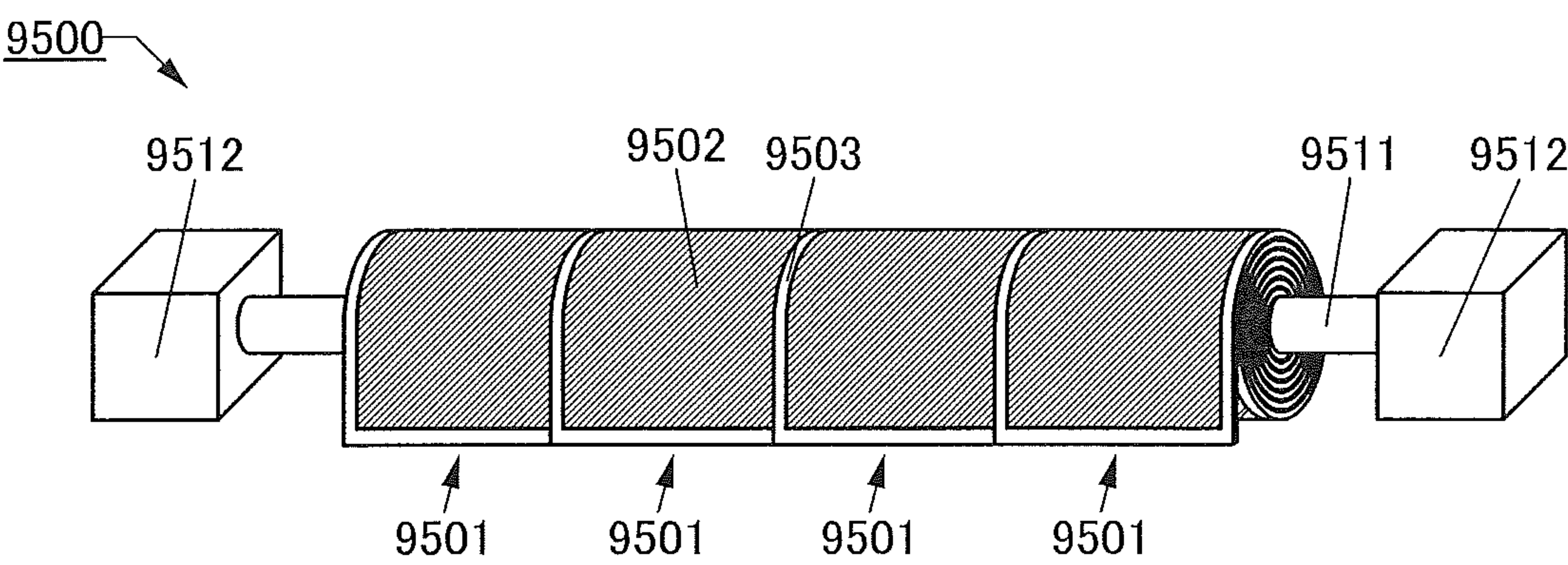


FIG. 29B

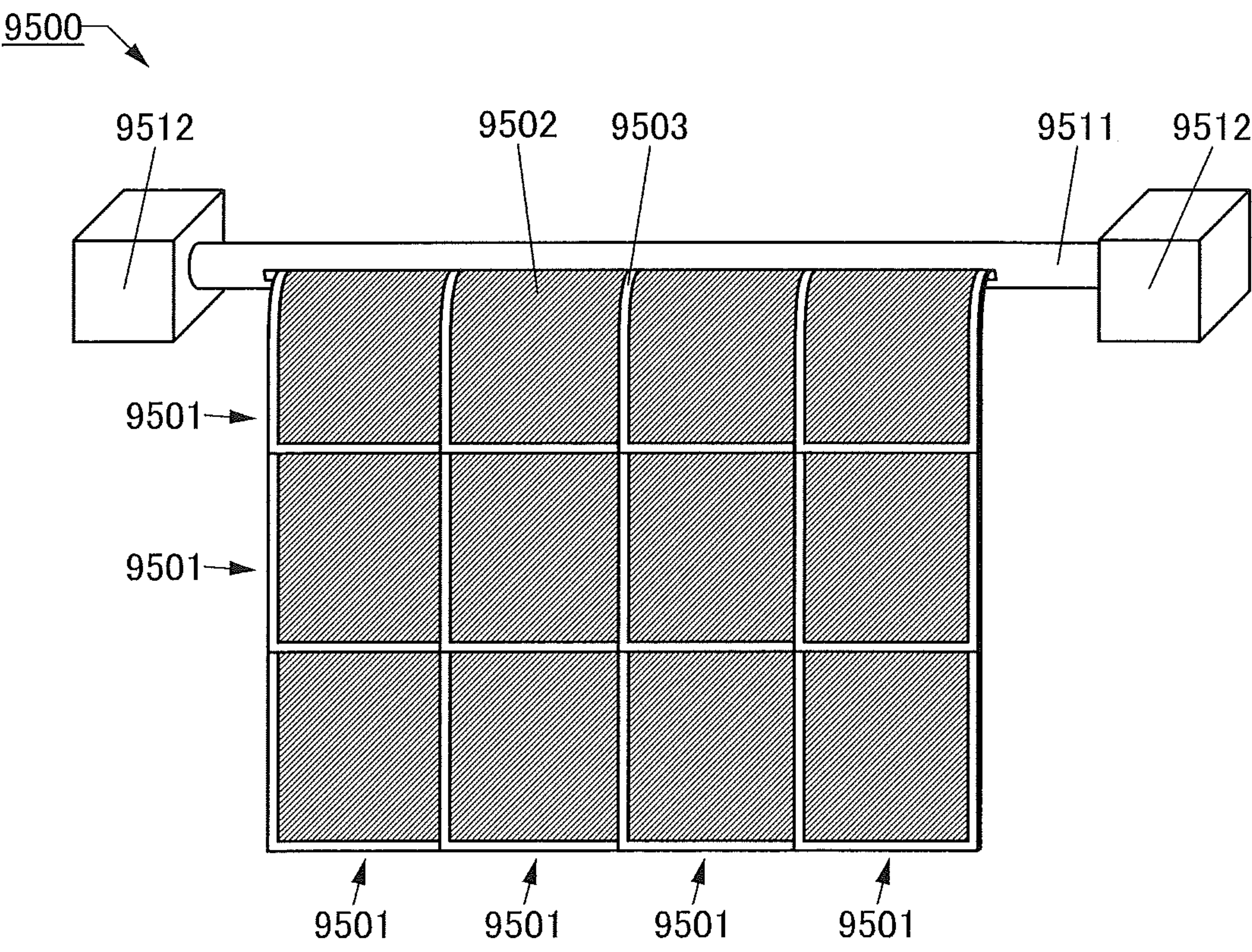


FIG. 30A

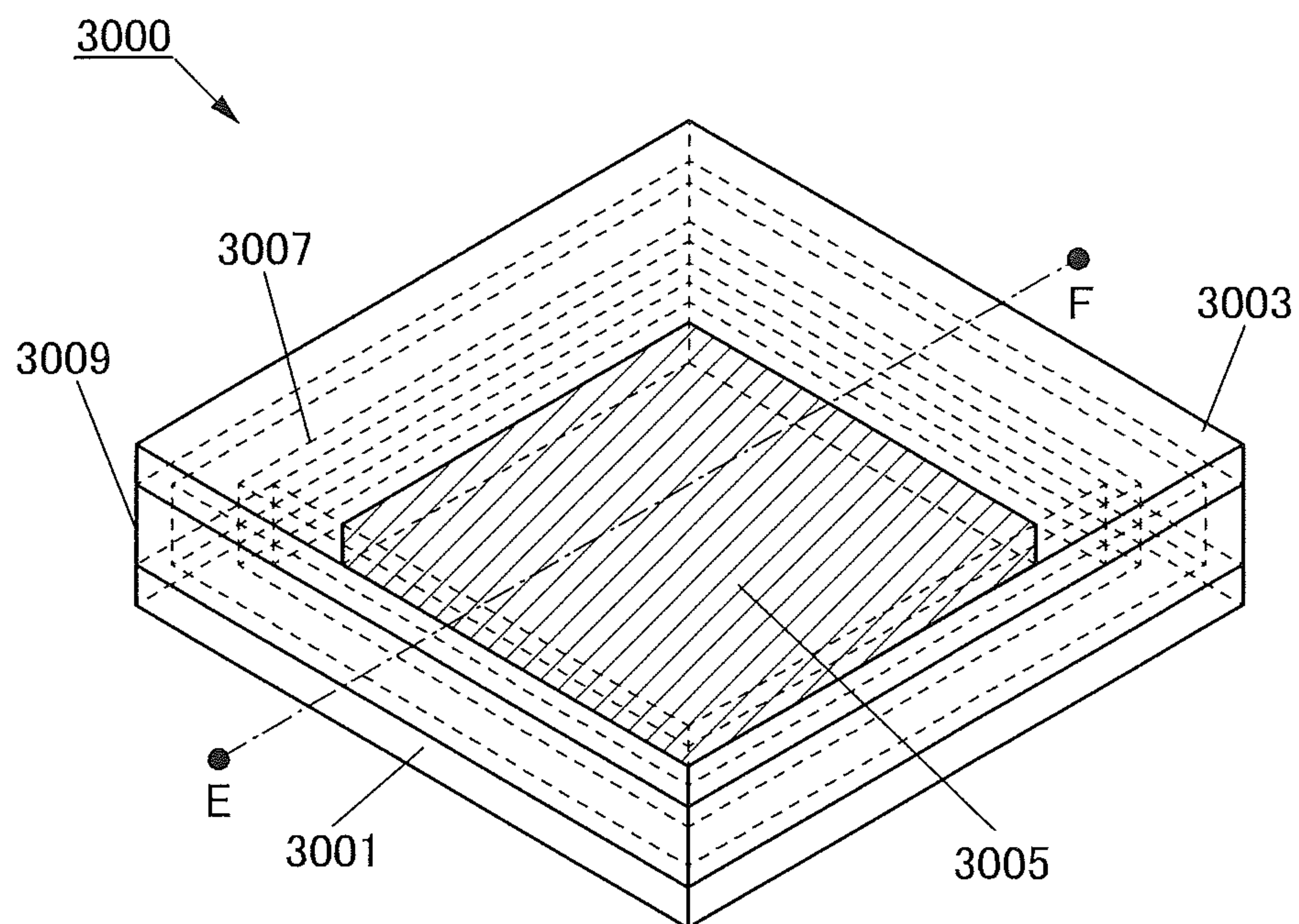


FIG. 30B

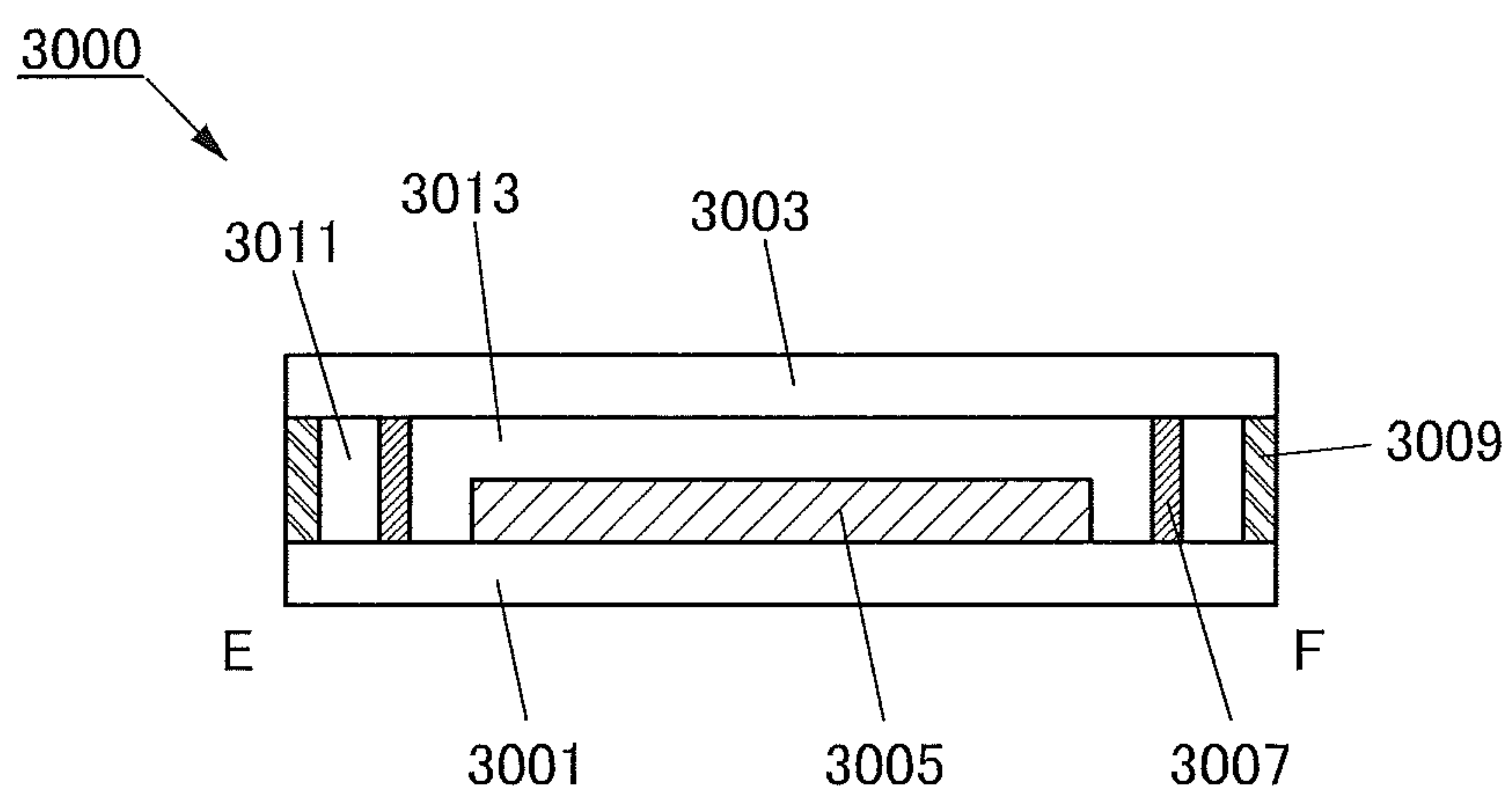


FIG. 30C

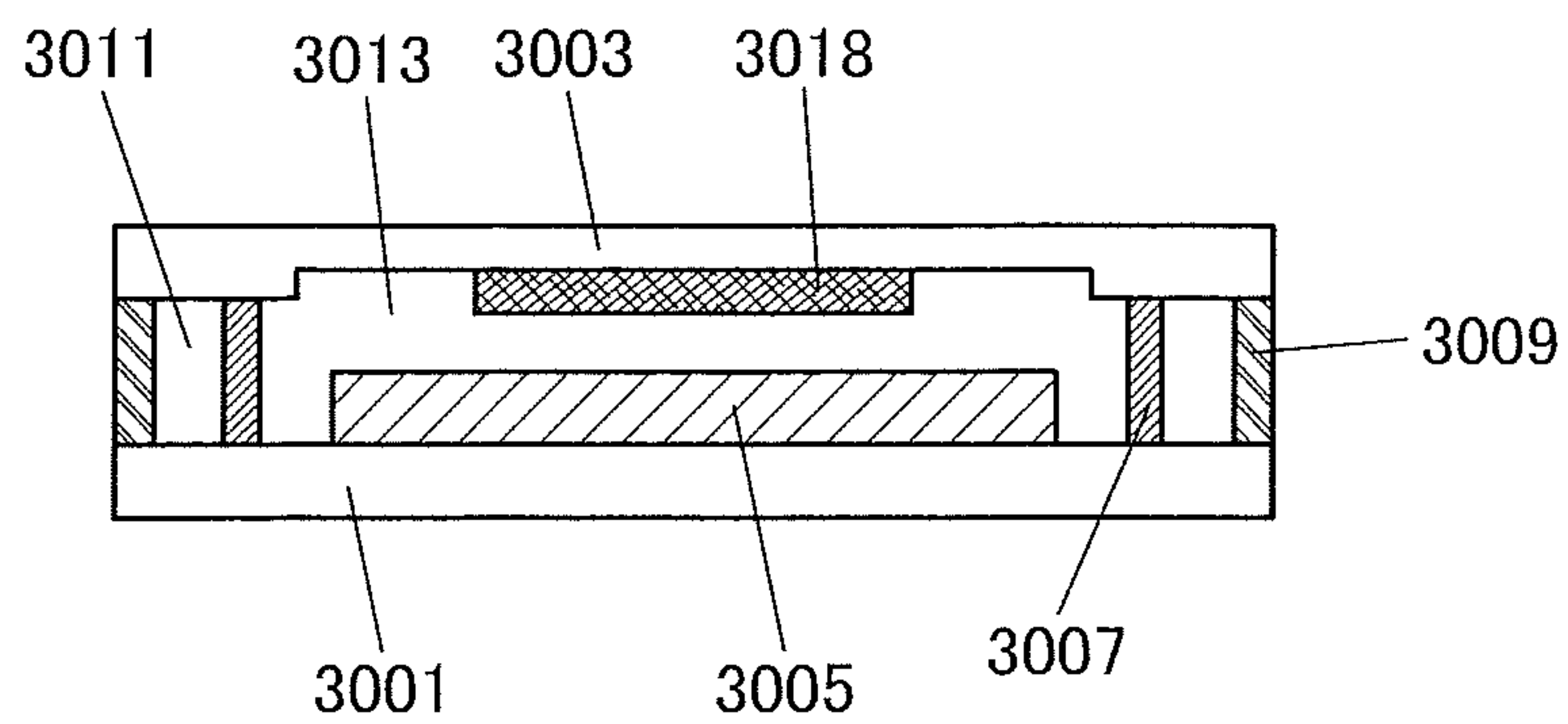


FIG. 31A

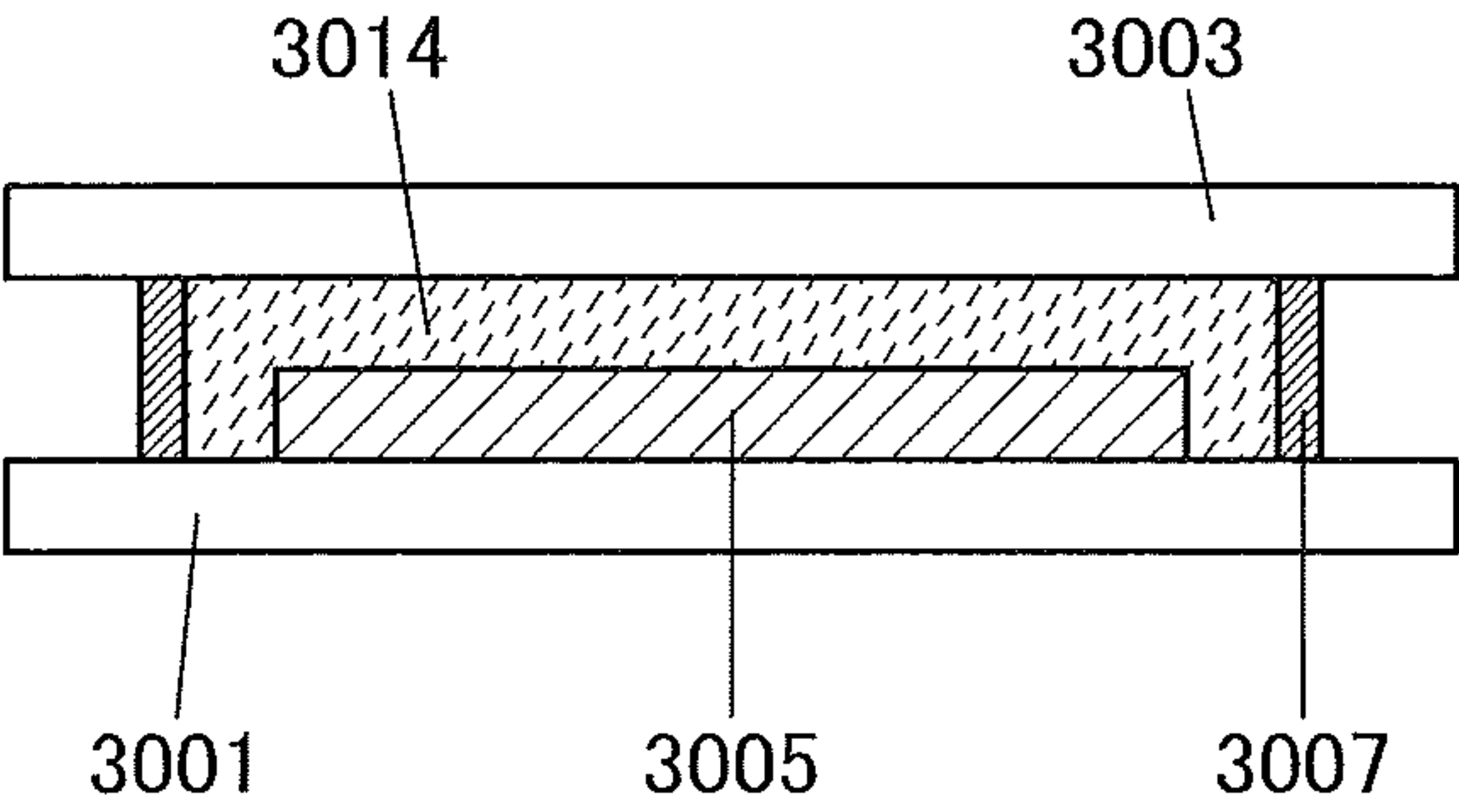


FIG. 31B

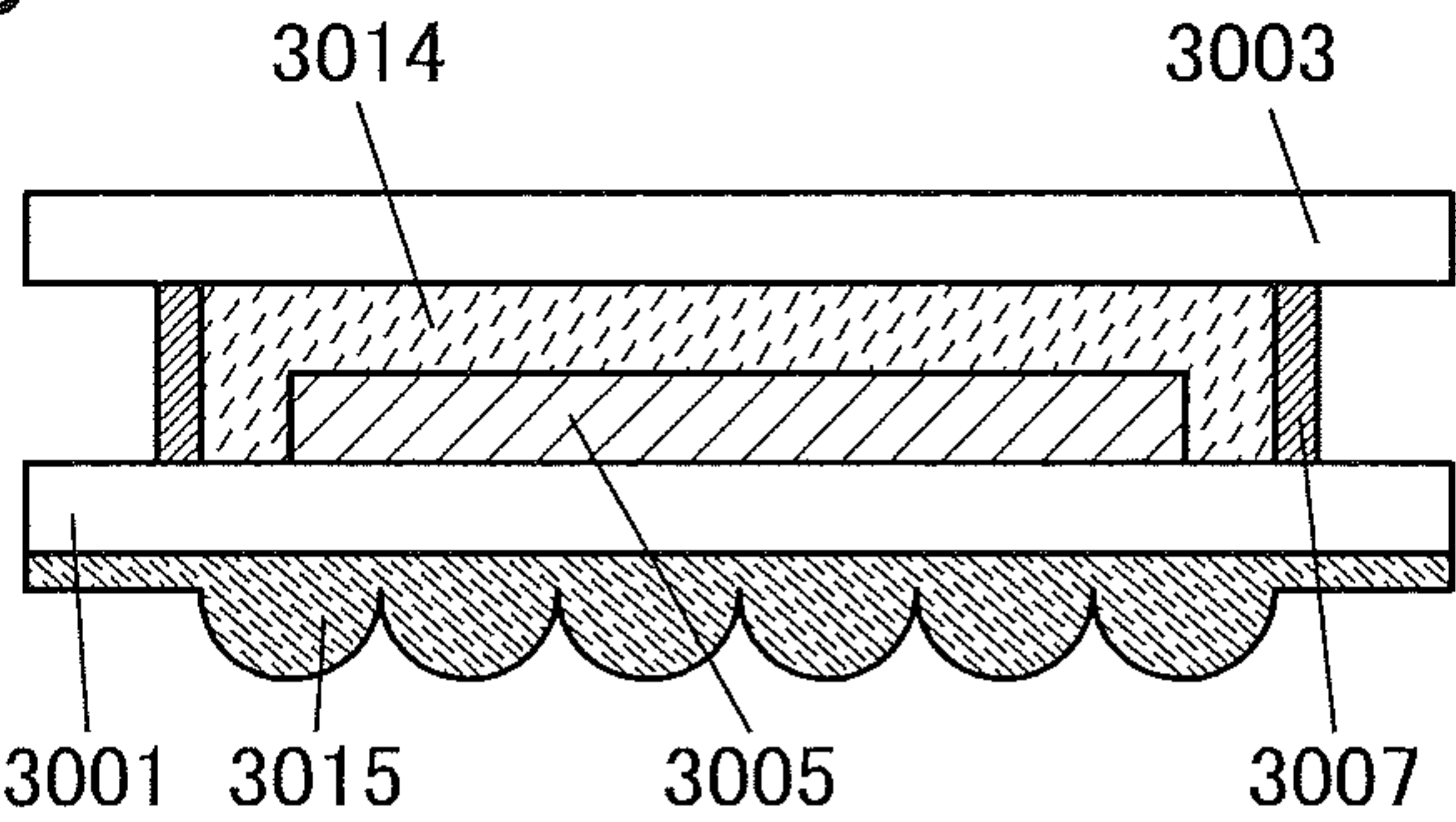


FIG. 31C

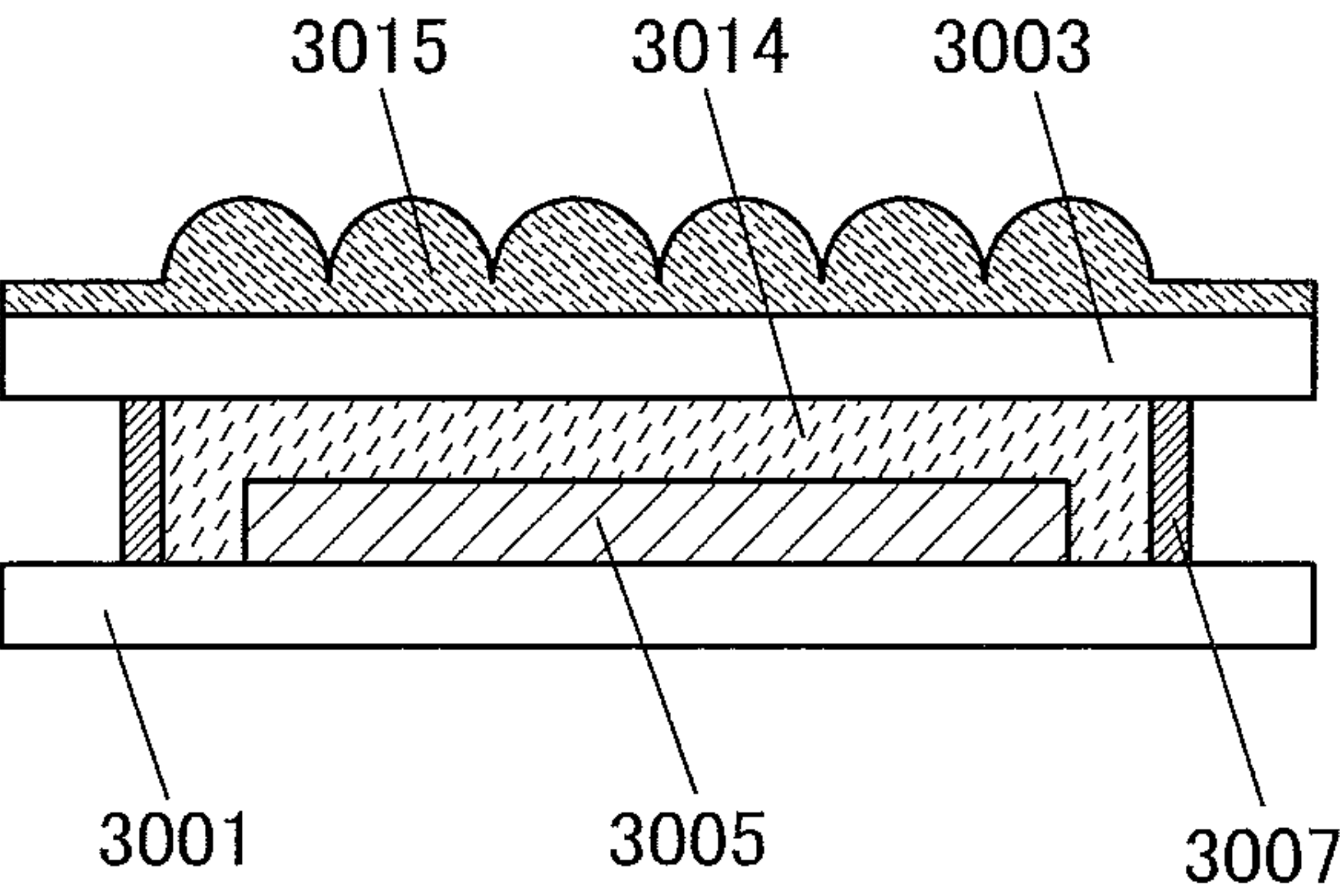


FIG. 31D

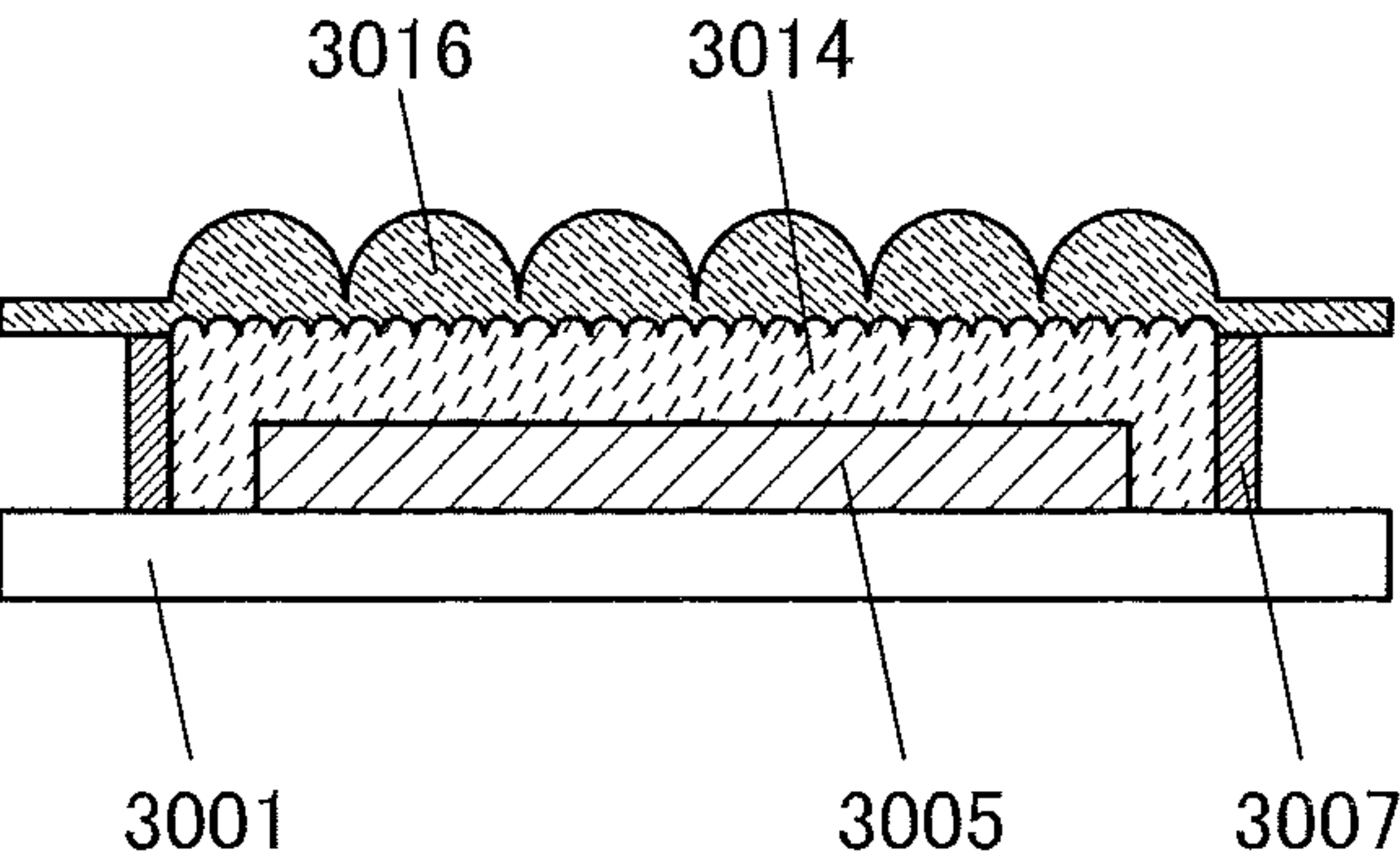


FIG. 32A

3500

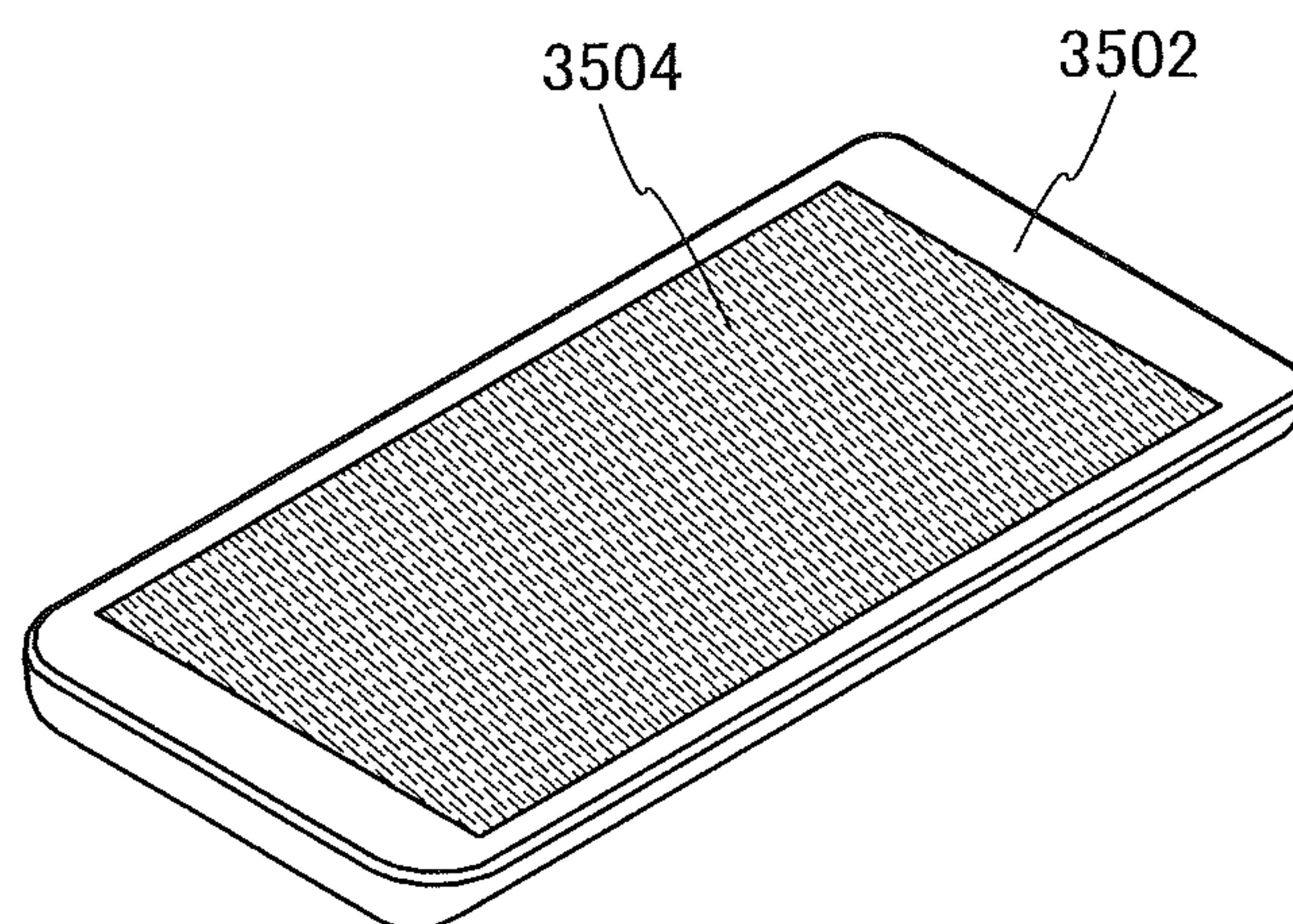


FIG. 32B

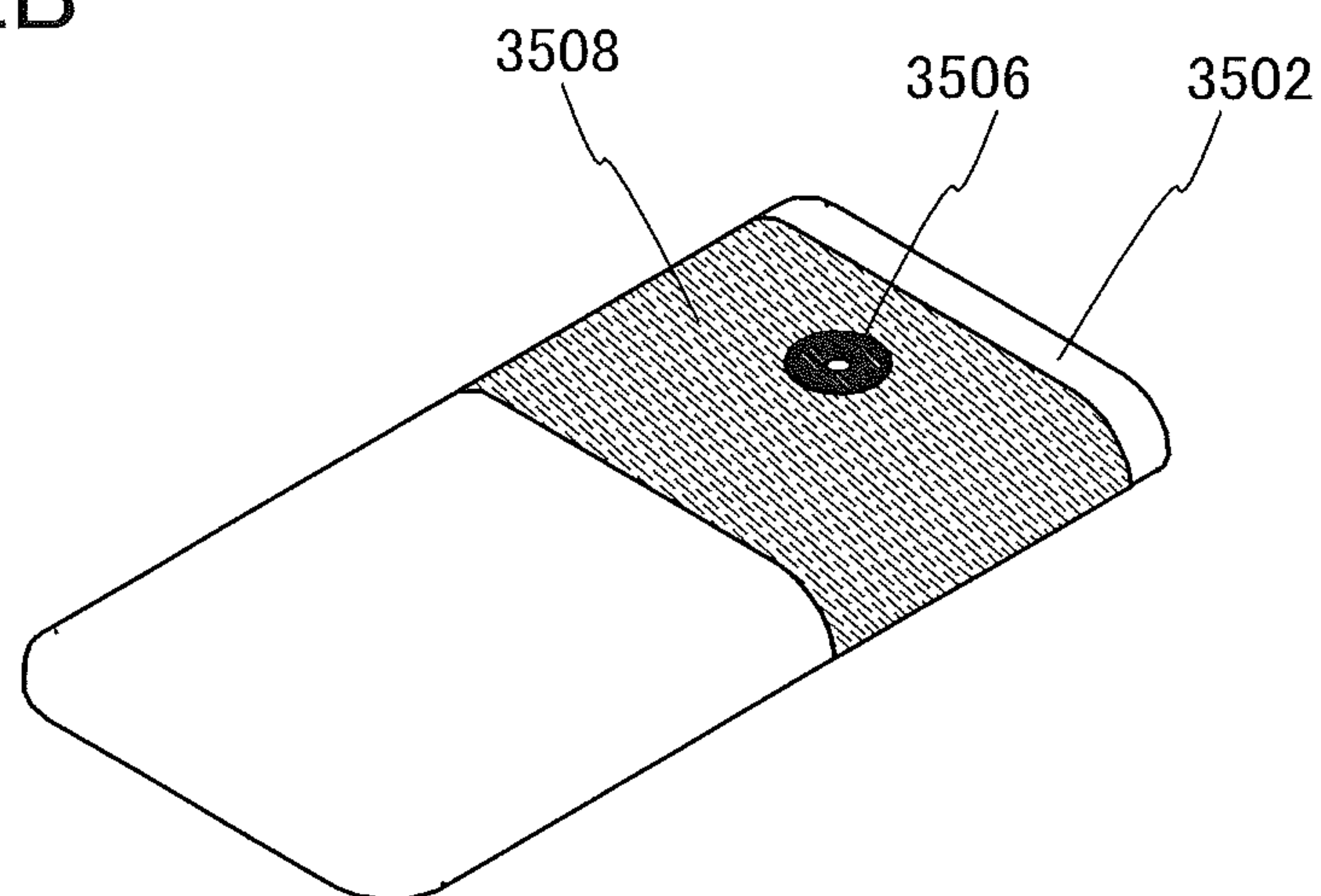


FIG. 32C

3600

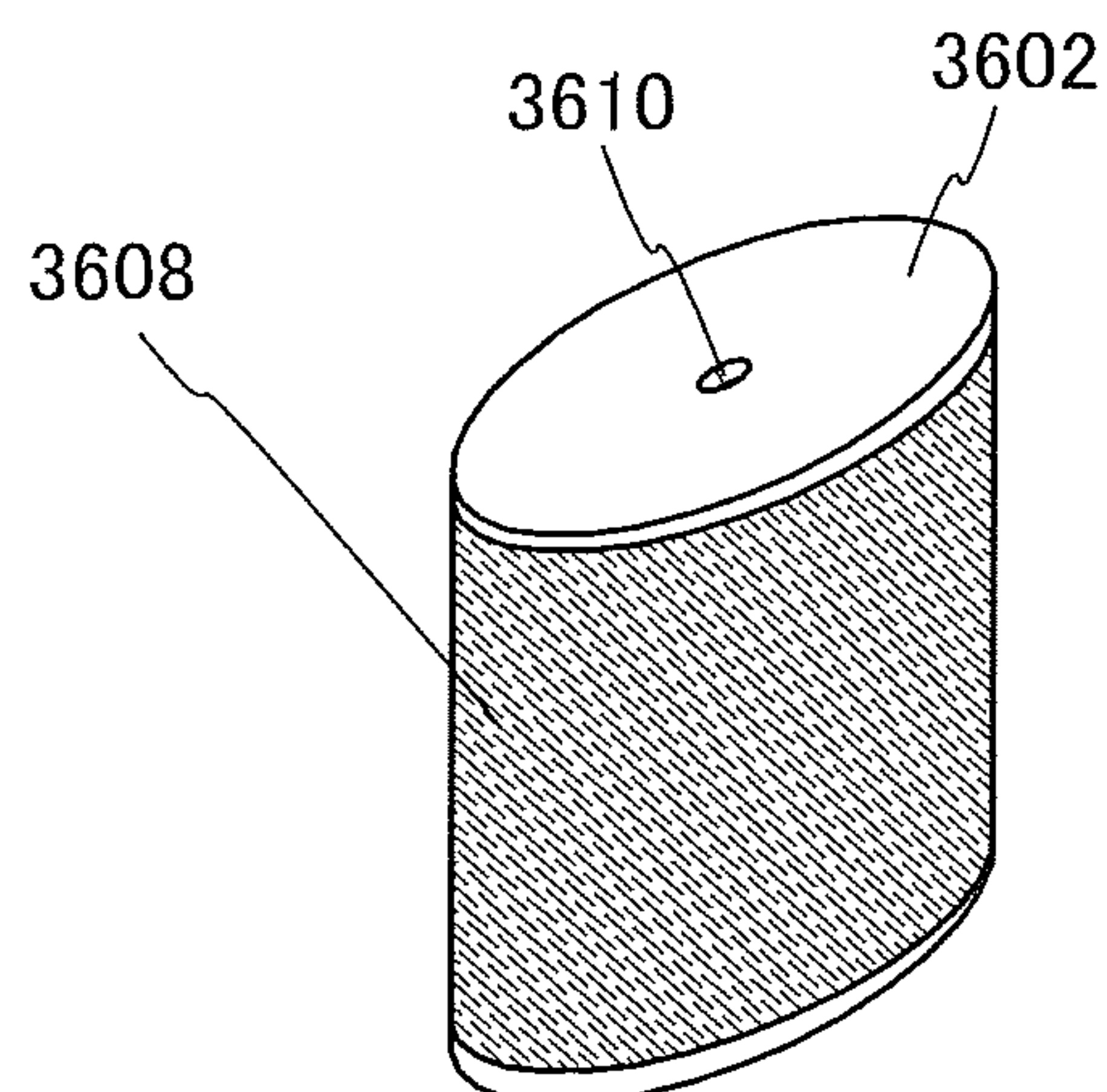


FIG. 33

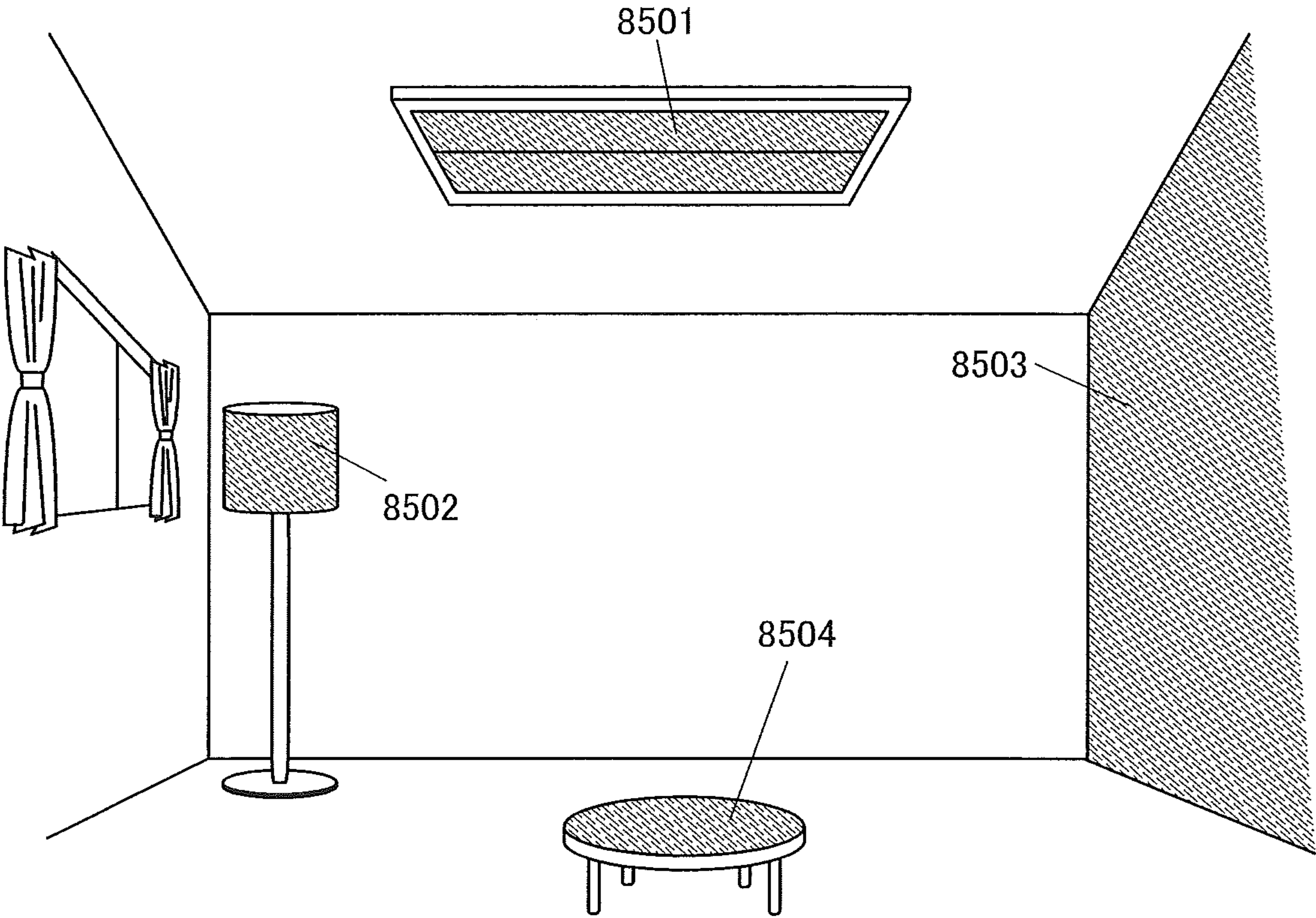


FIG. 34

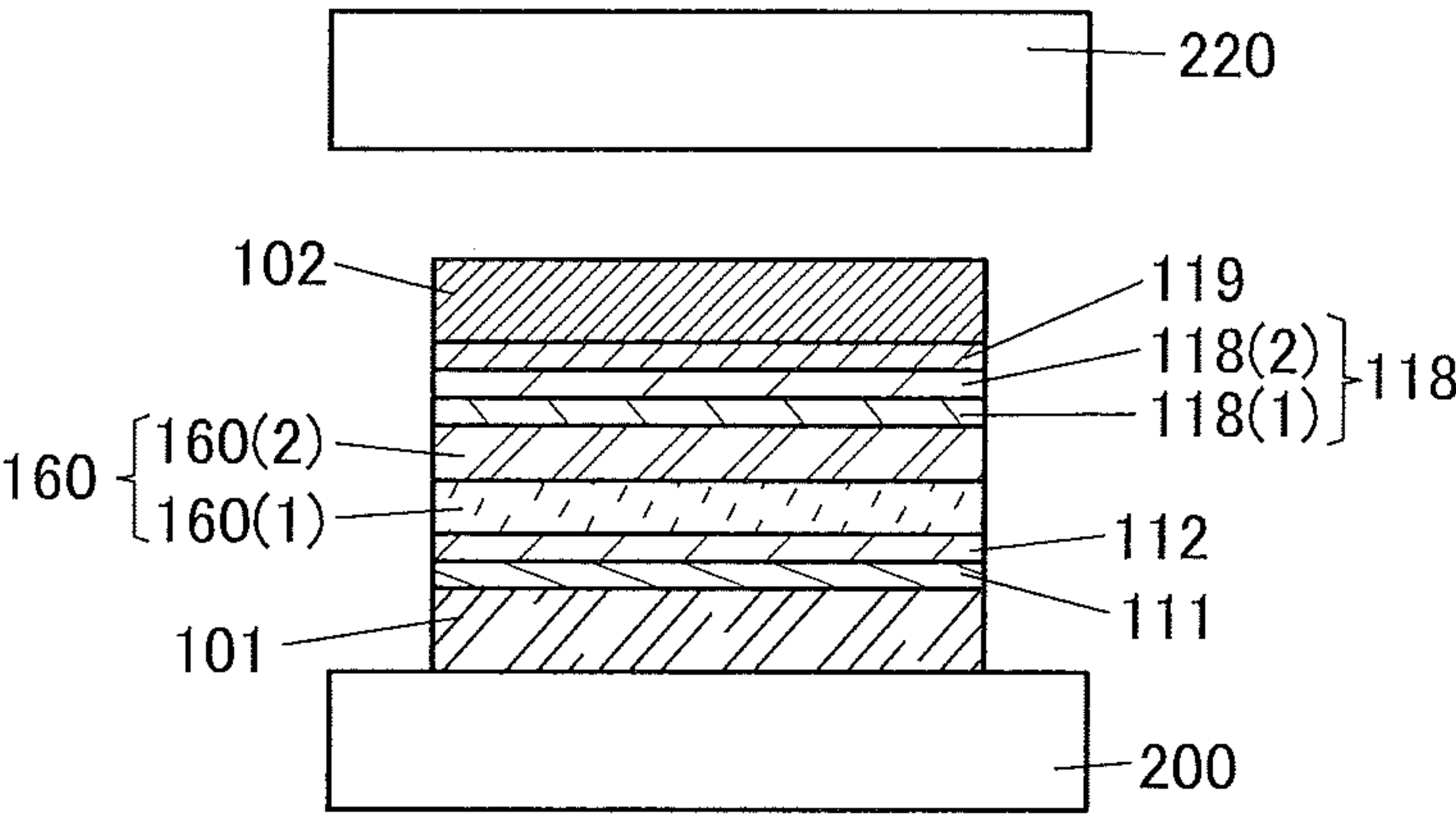


FIG. 35

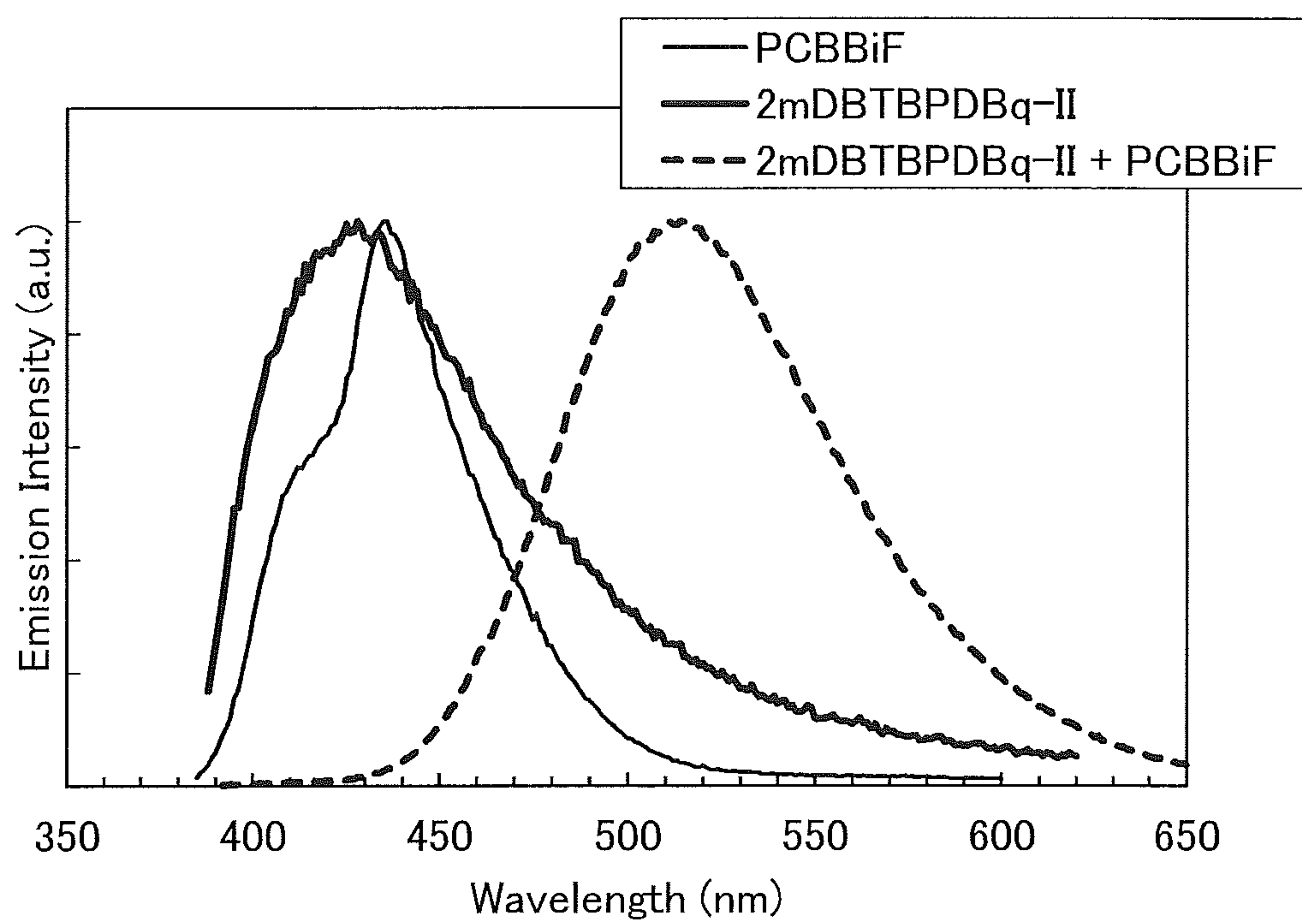


FIG. 36

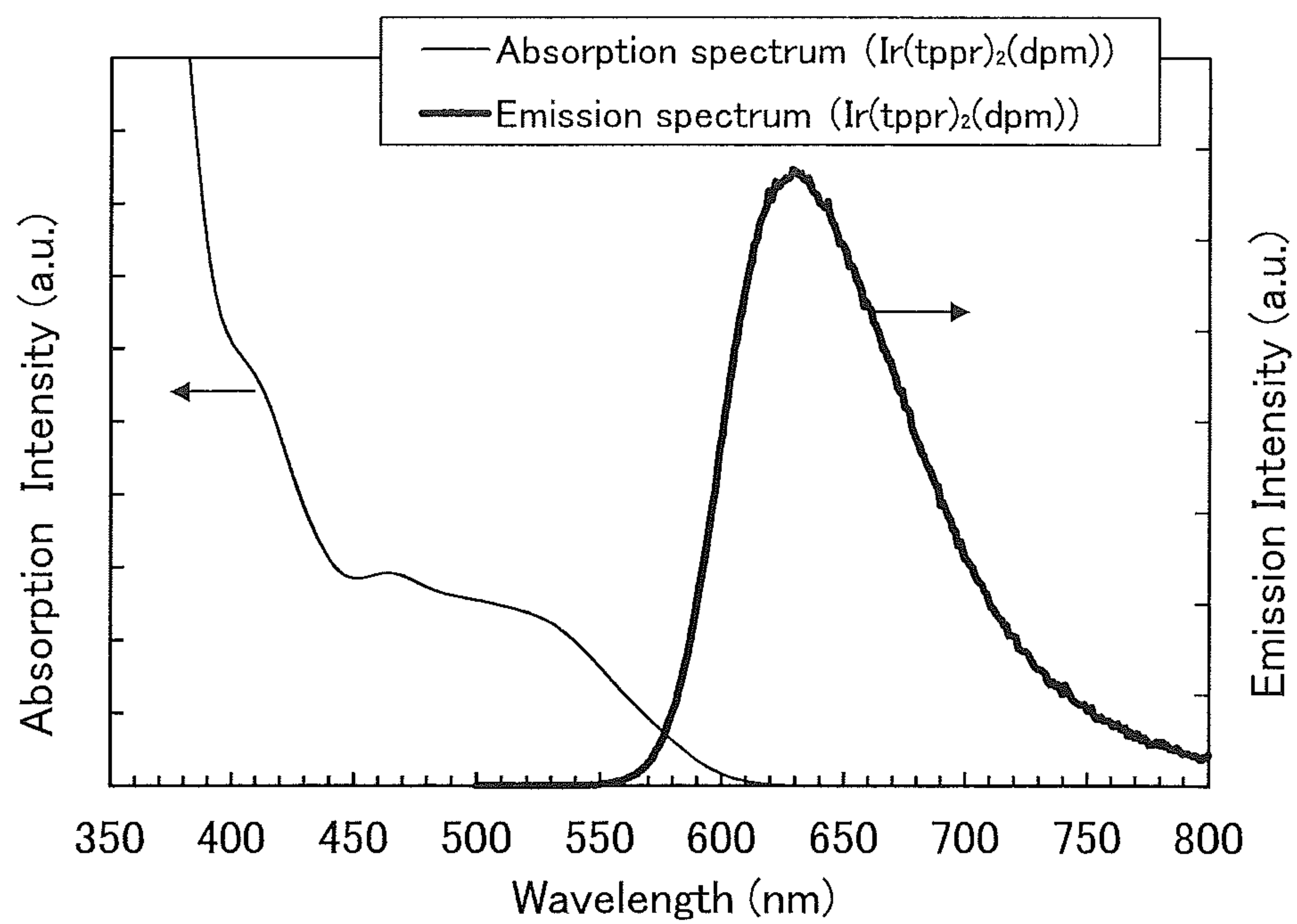


FIG. 37

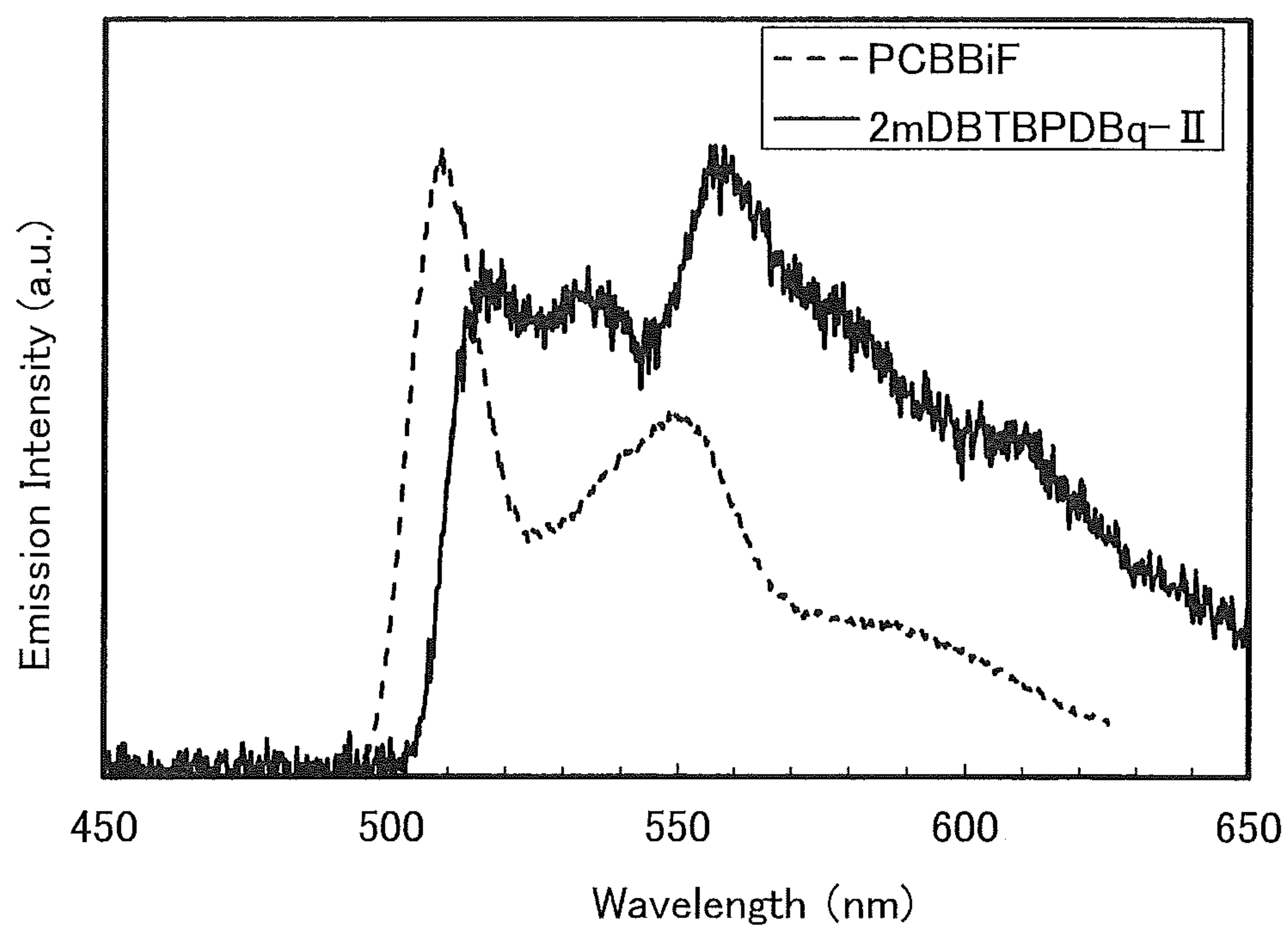


FIG. 38

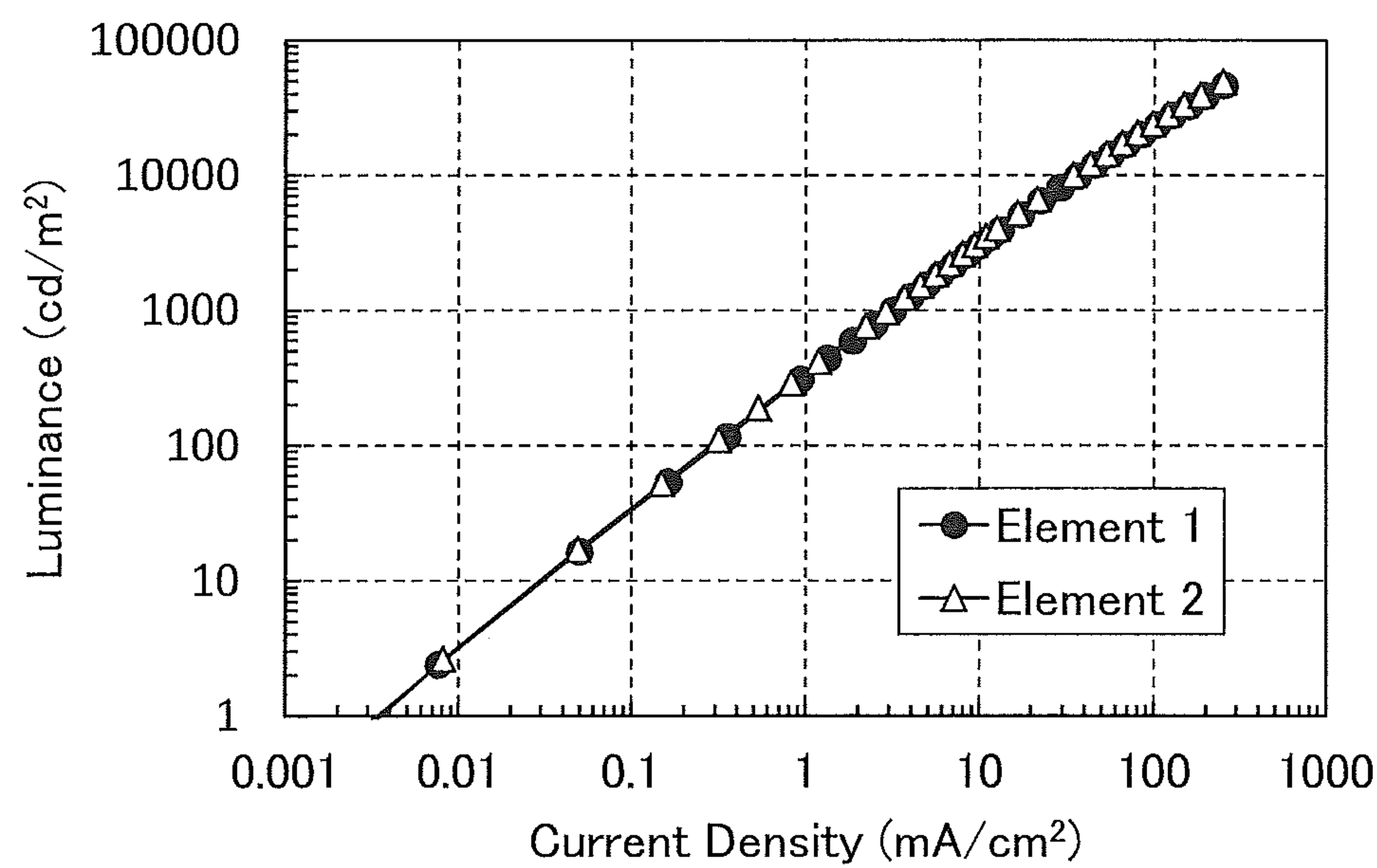


FIG. 39

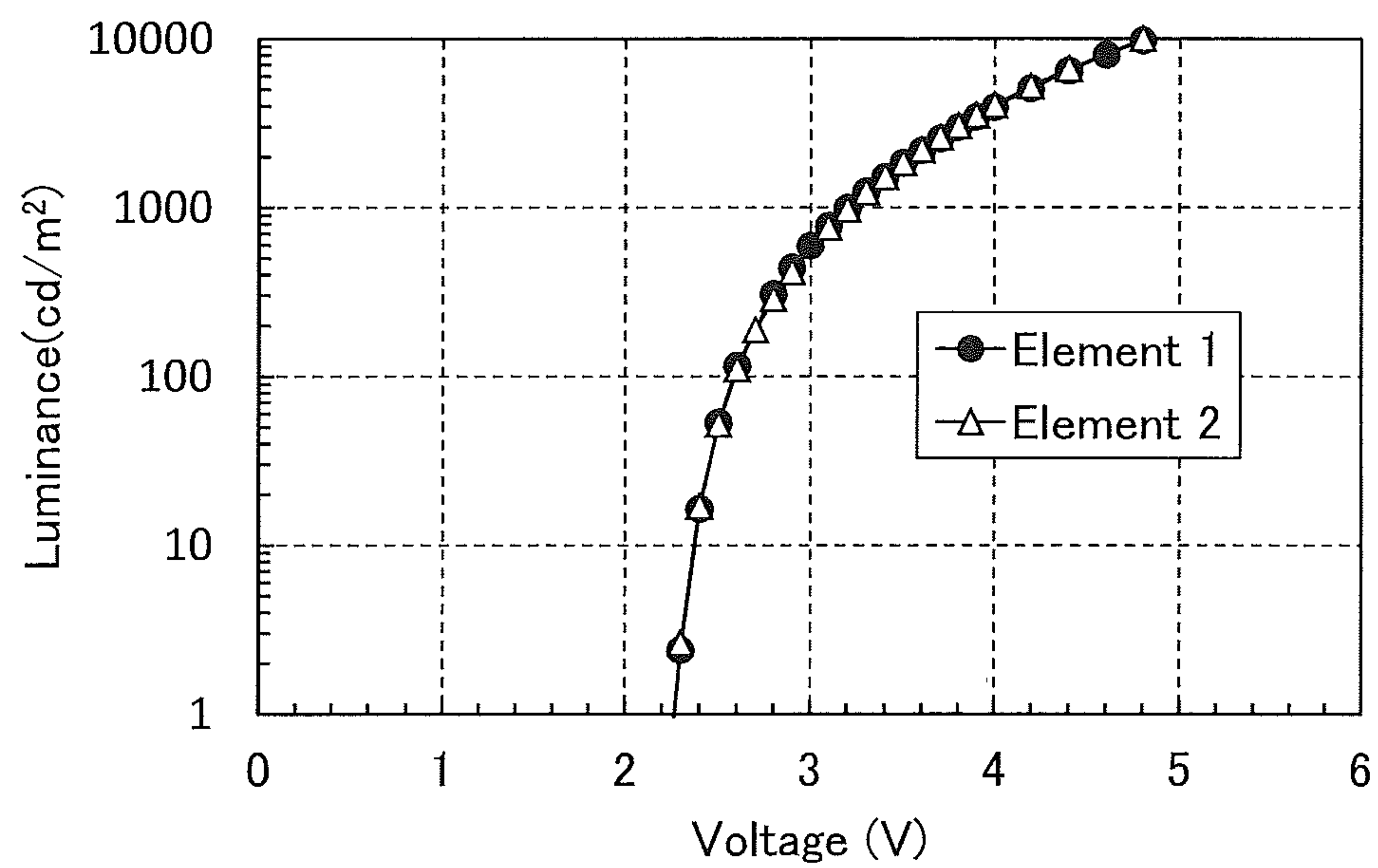


FIG. 40

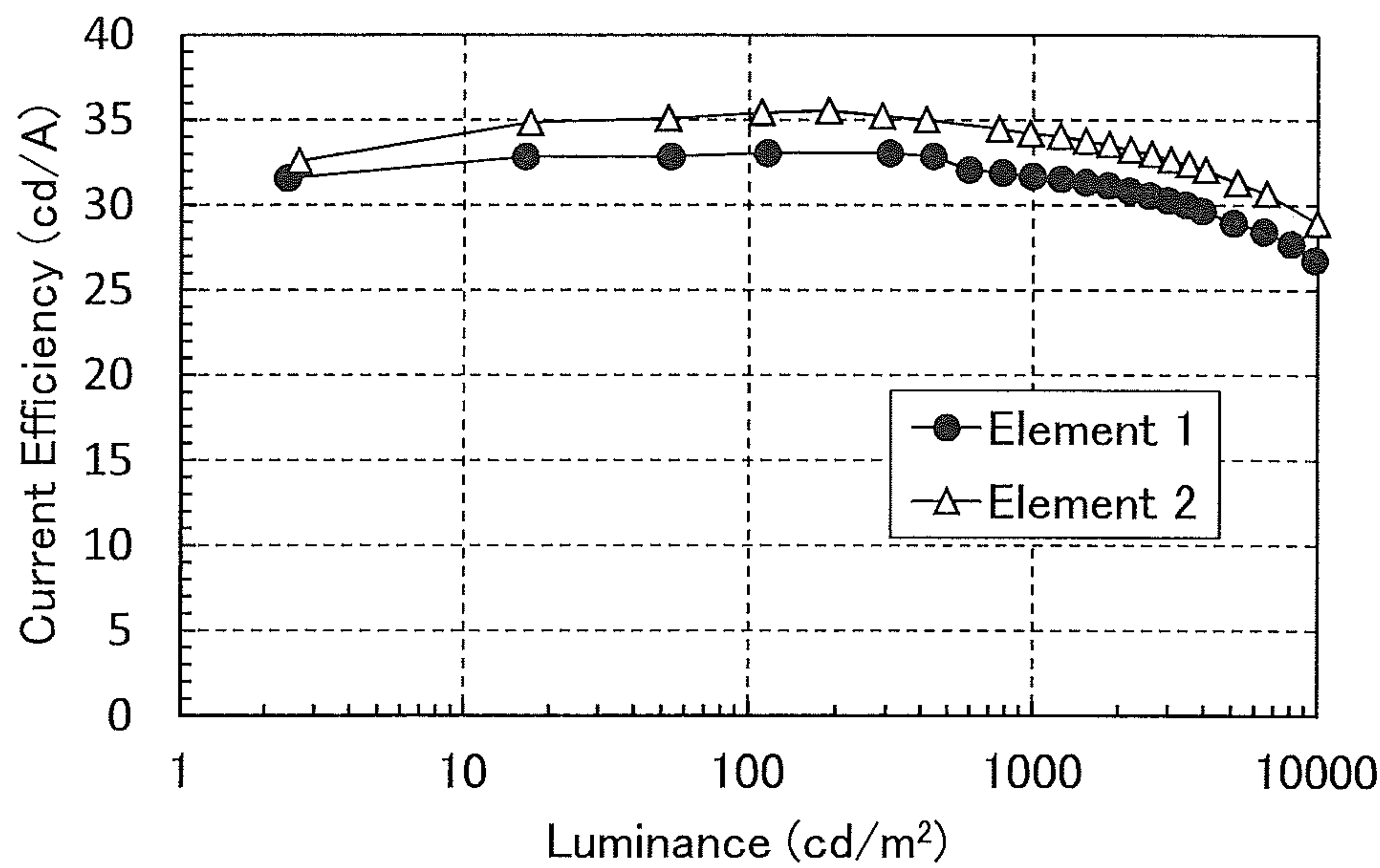


FIG. 41

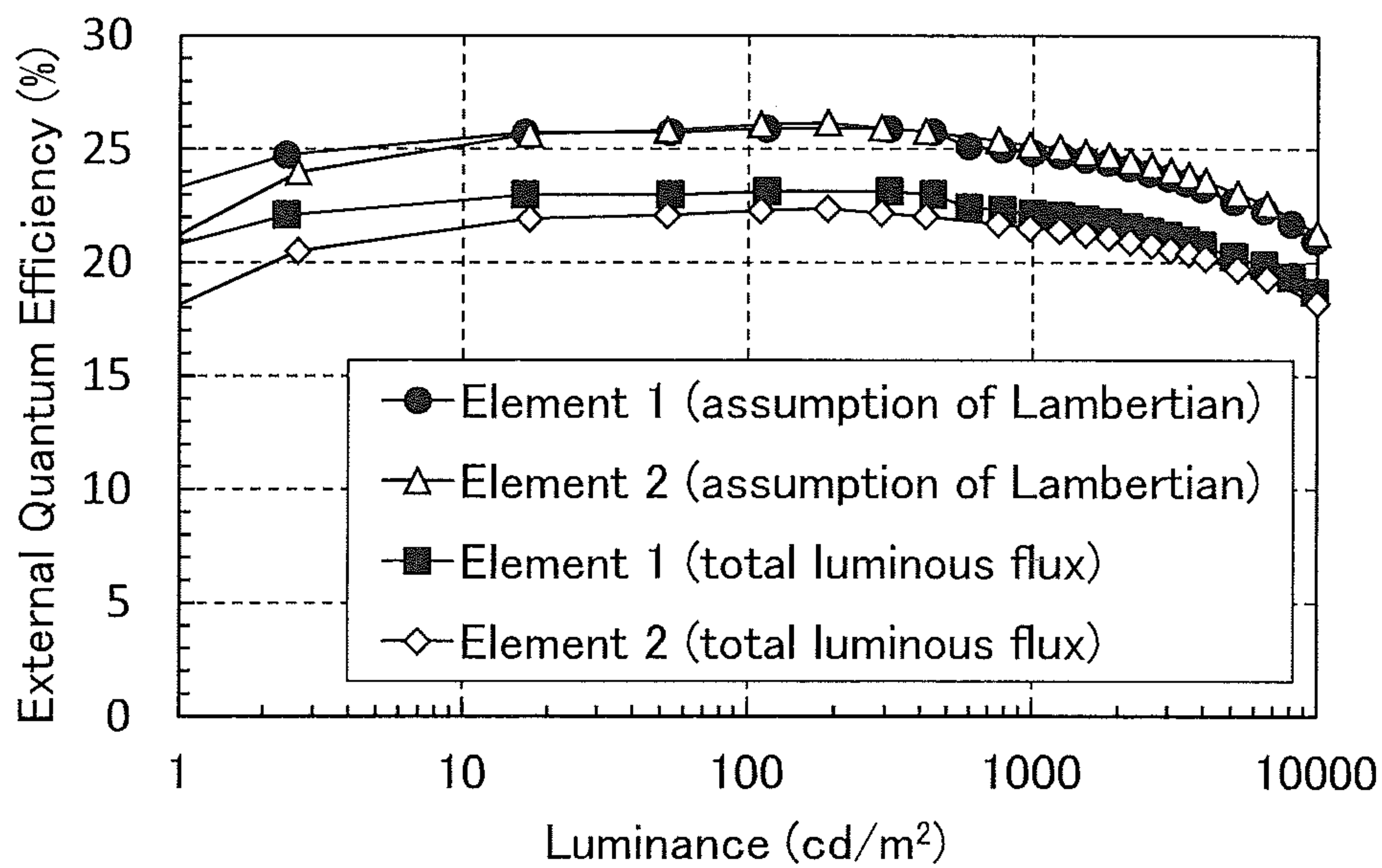


FIG. 42

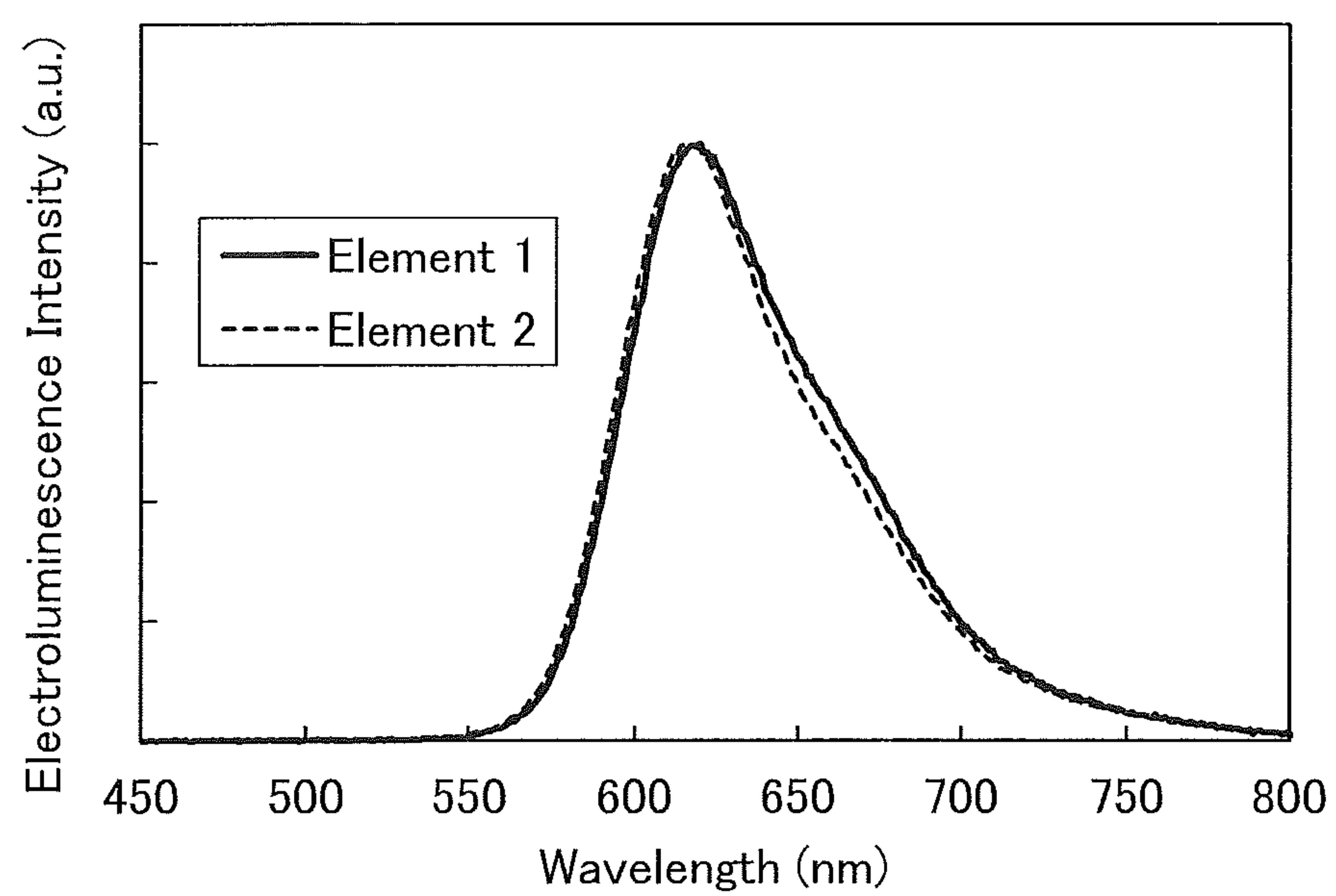


FIG. 43

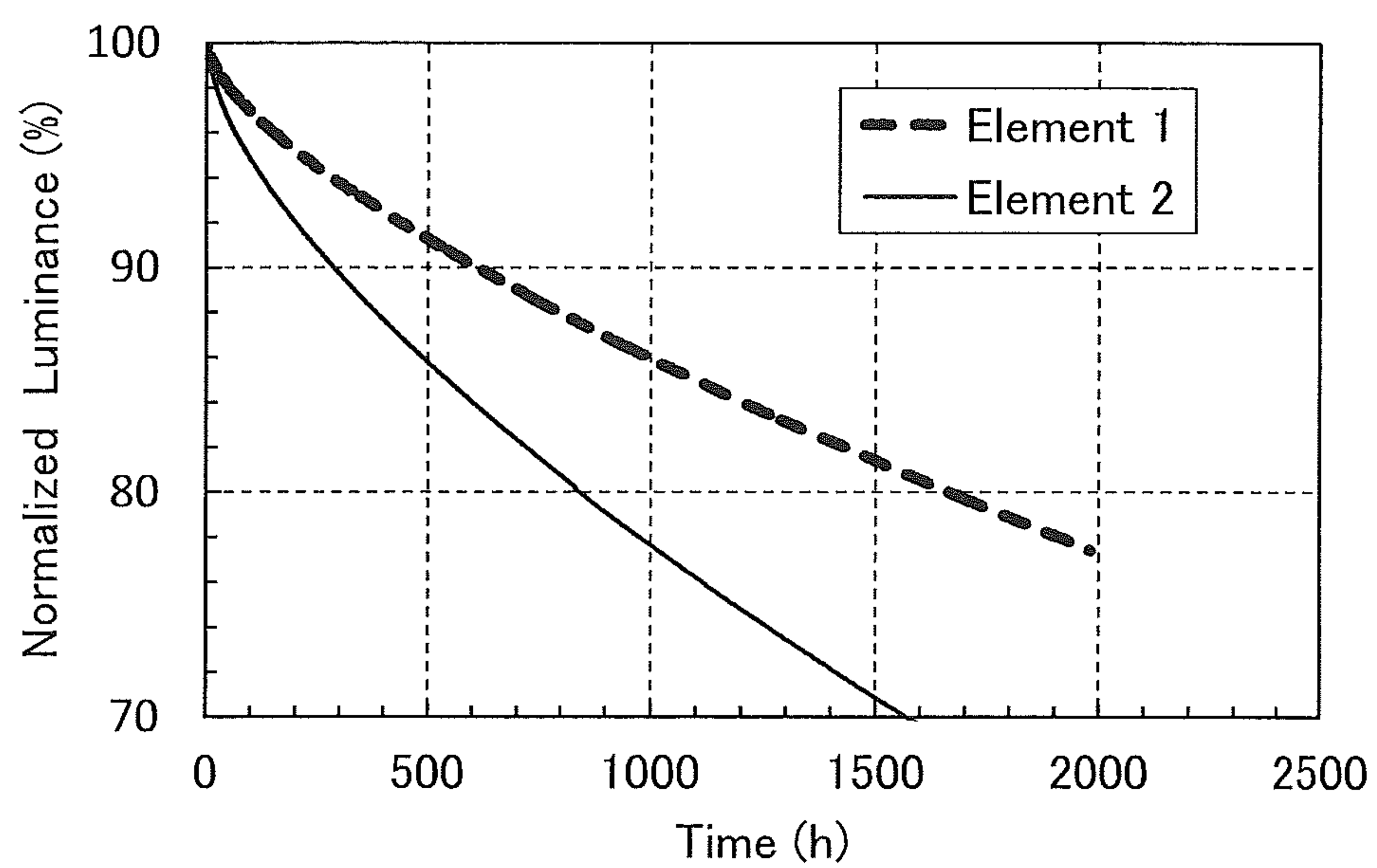


FIG. 44

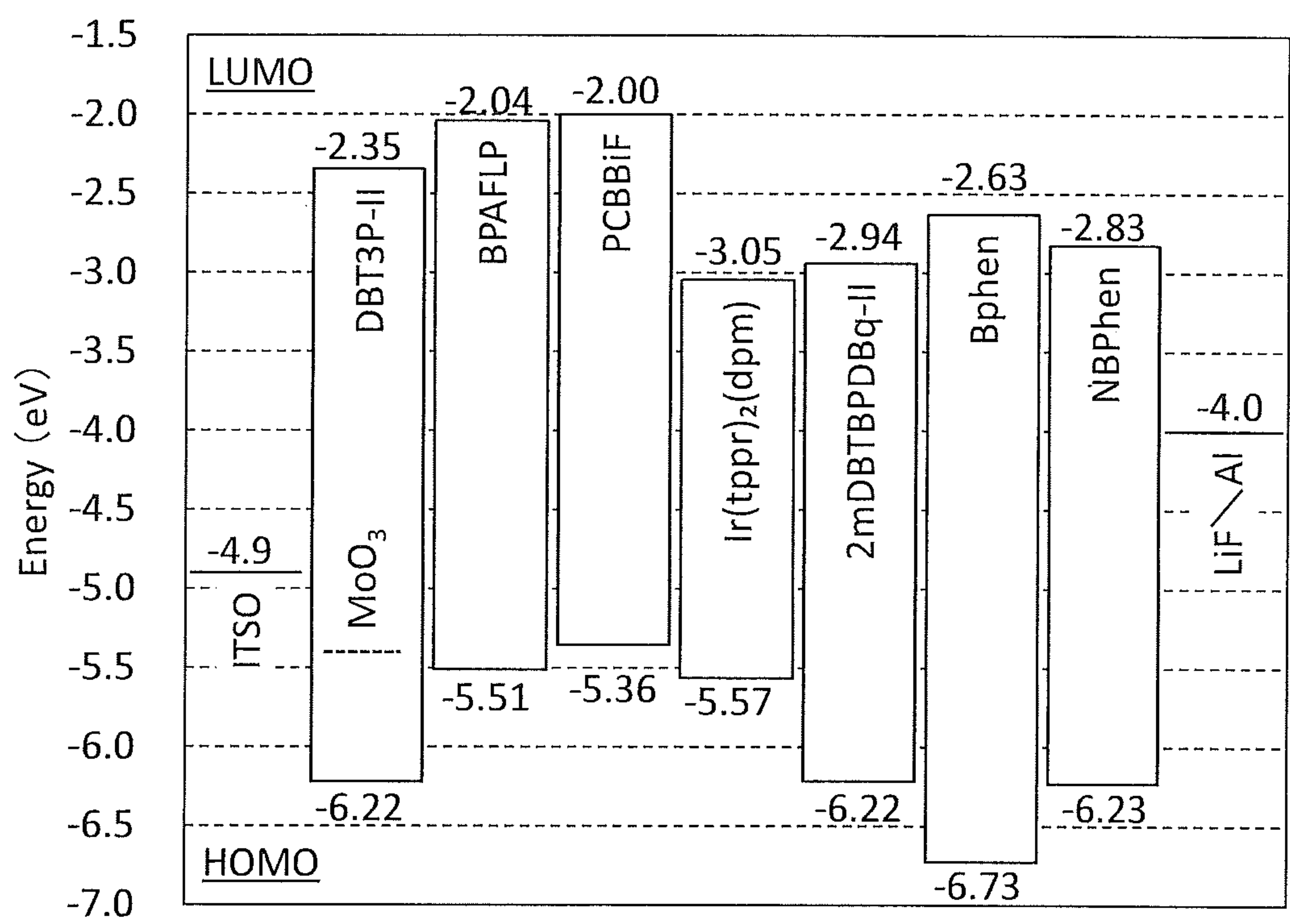


FIG. 45

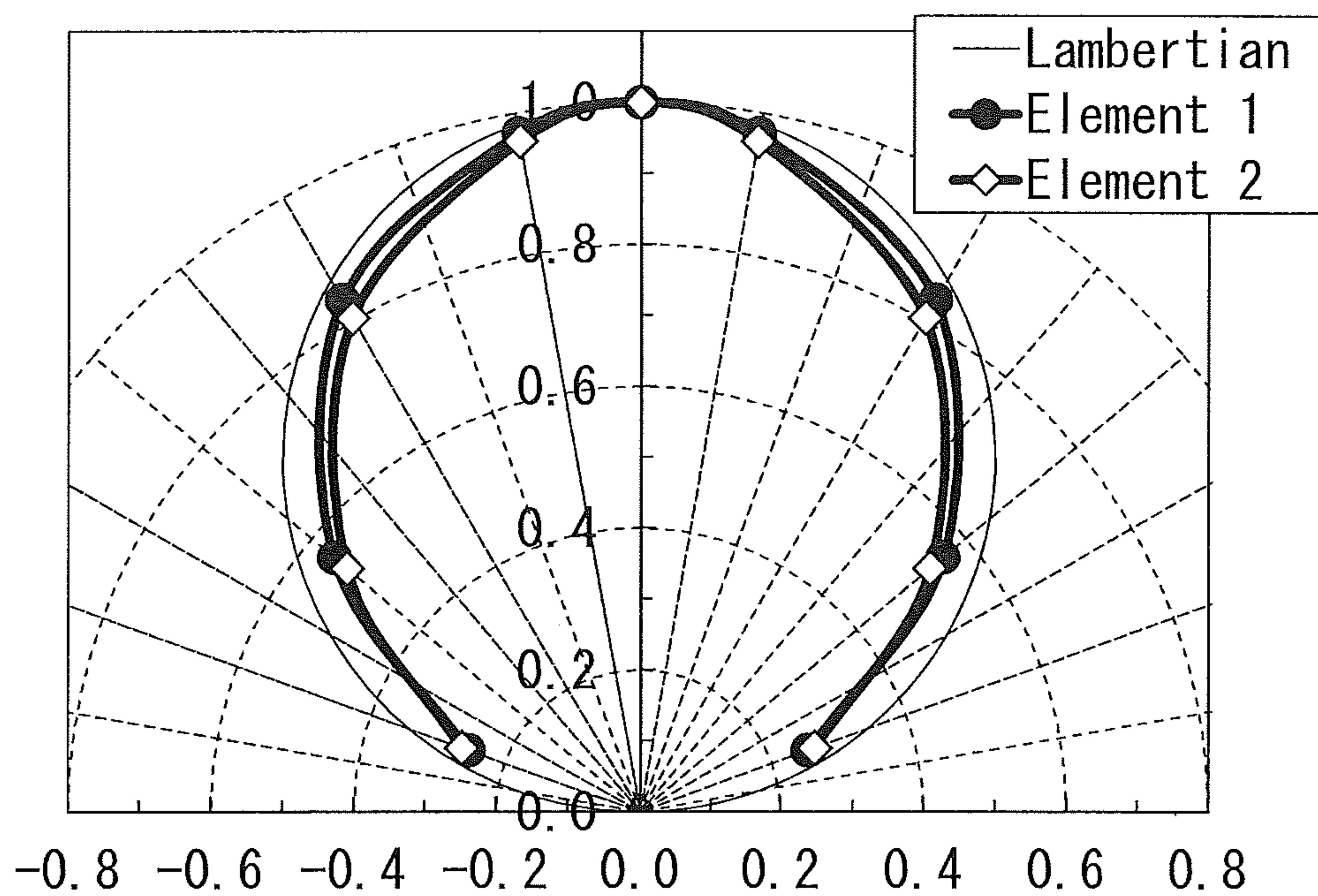


FIG. 46

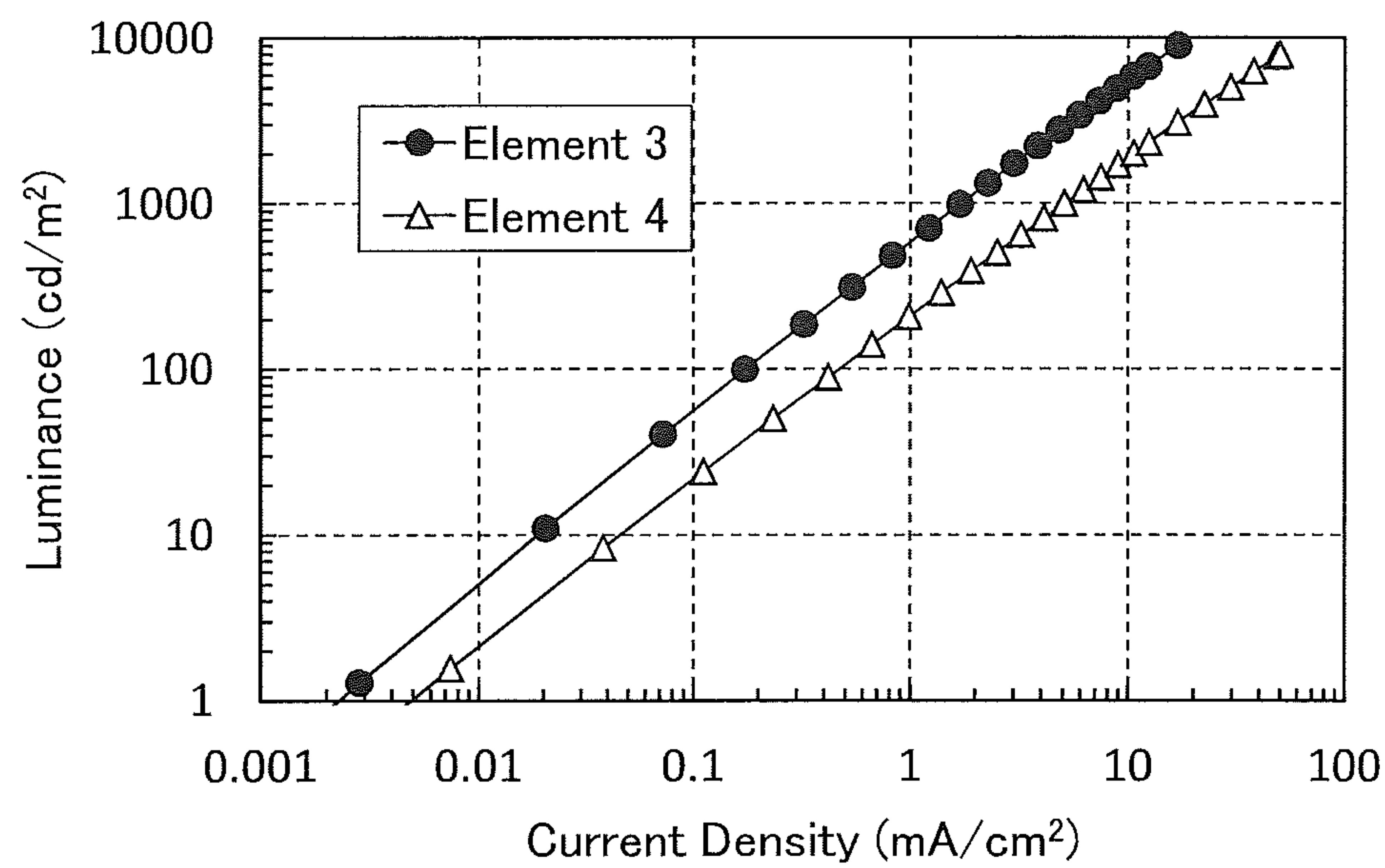


FIG. 47

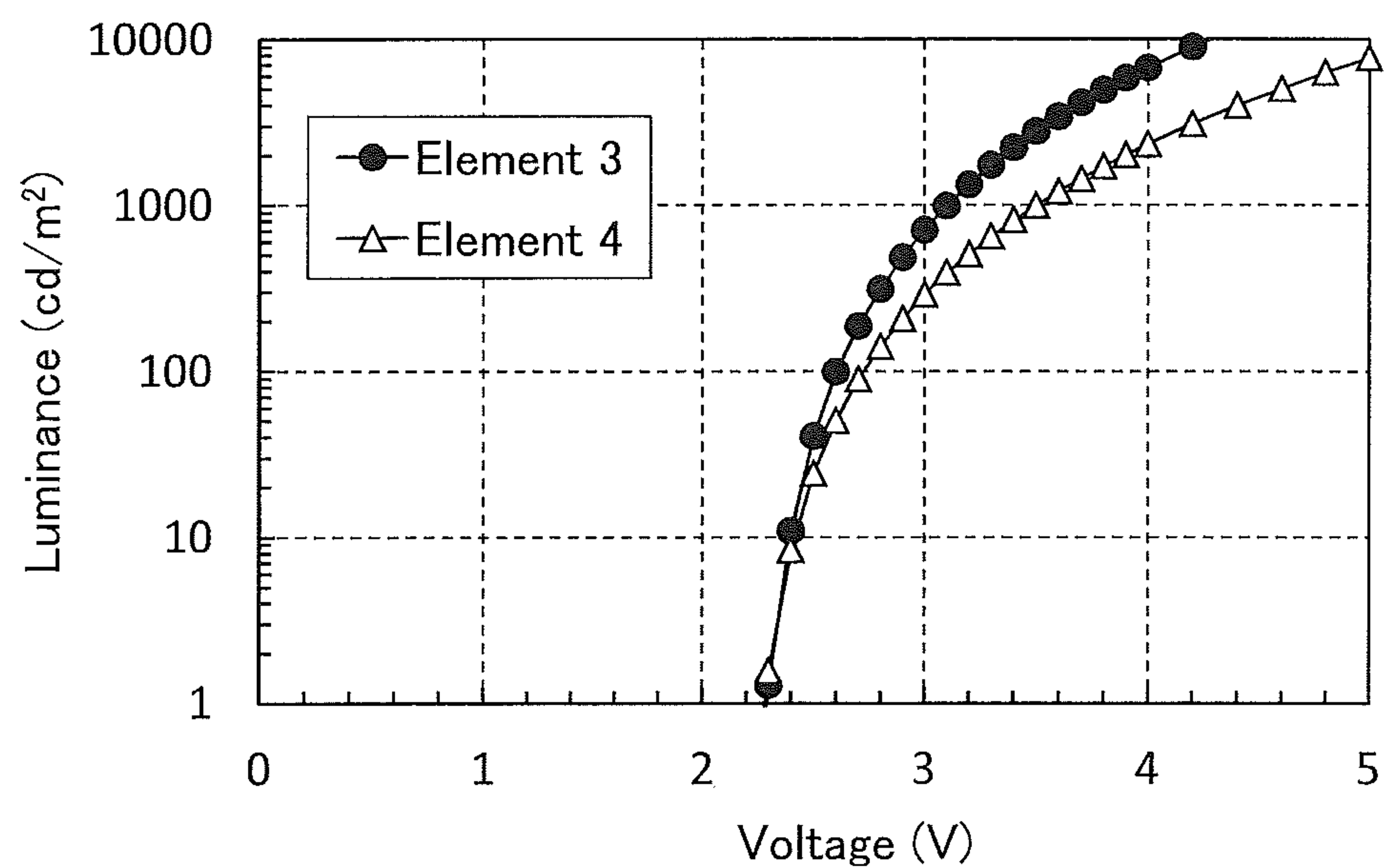


FIG. 48

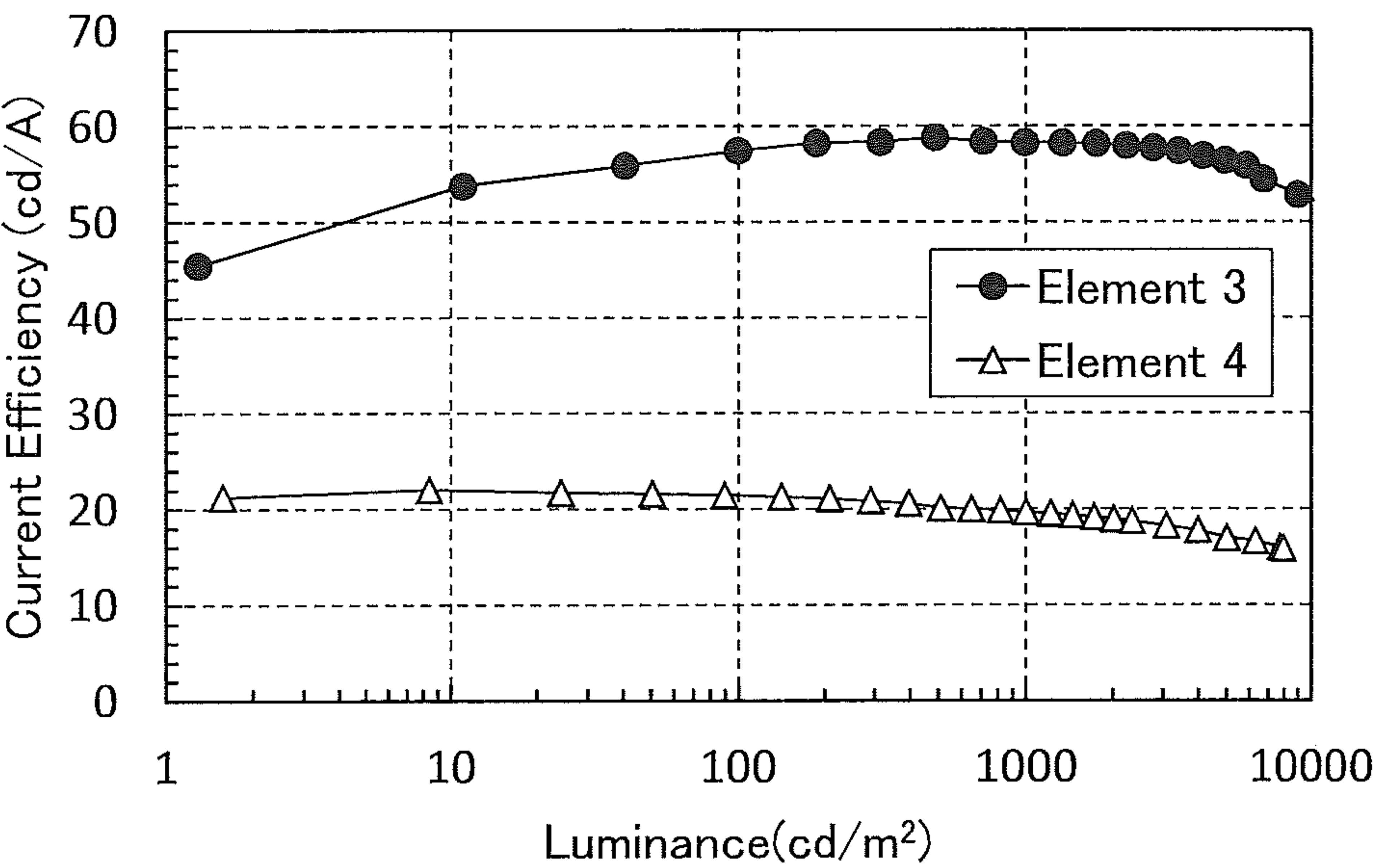


FIG. 49

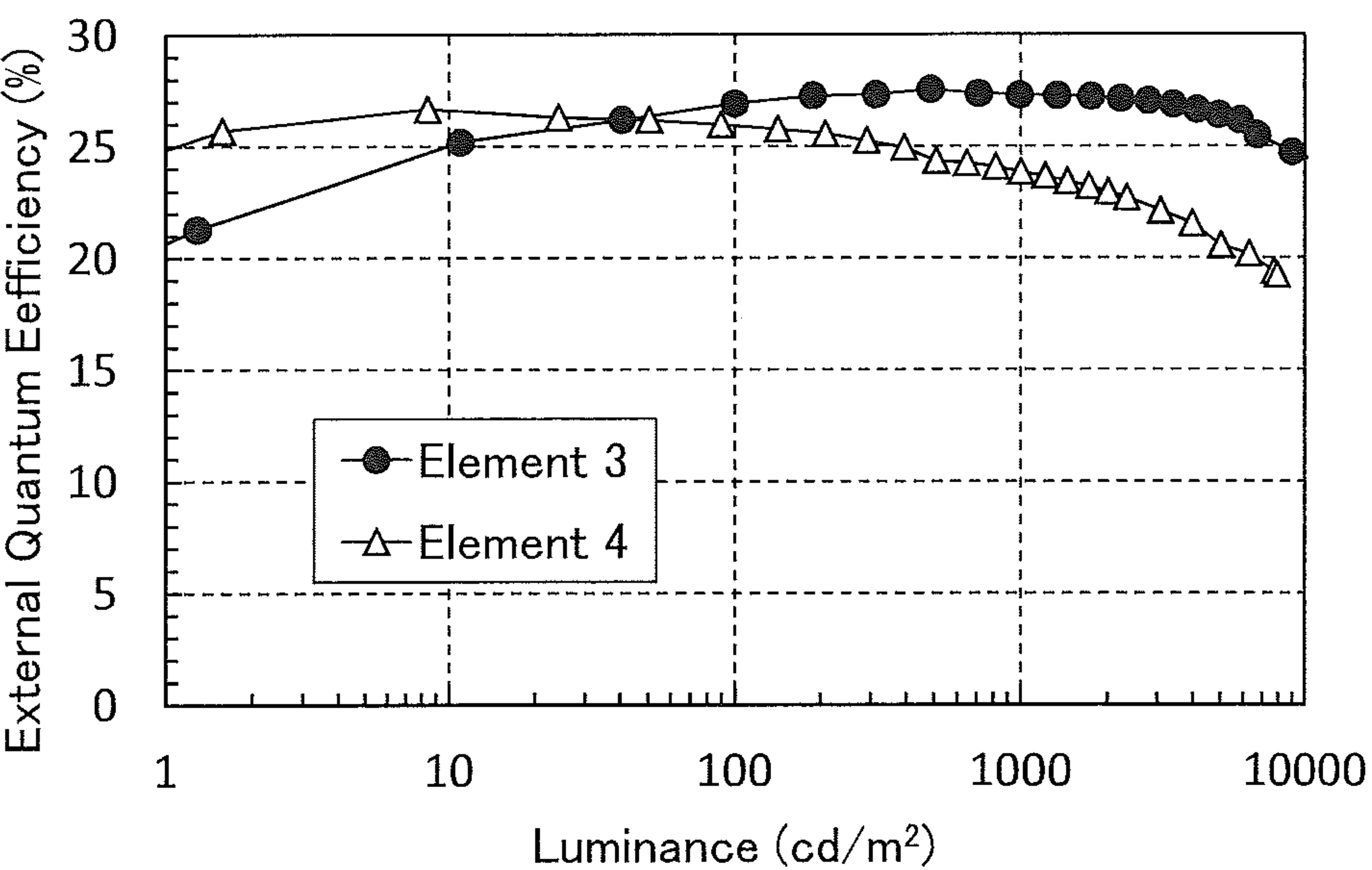


FIG. 50

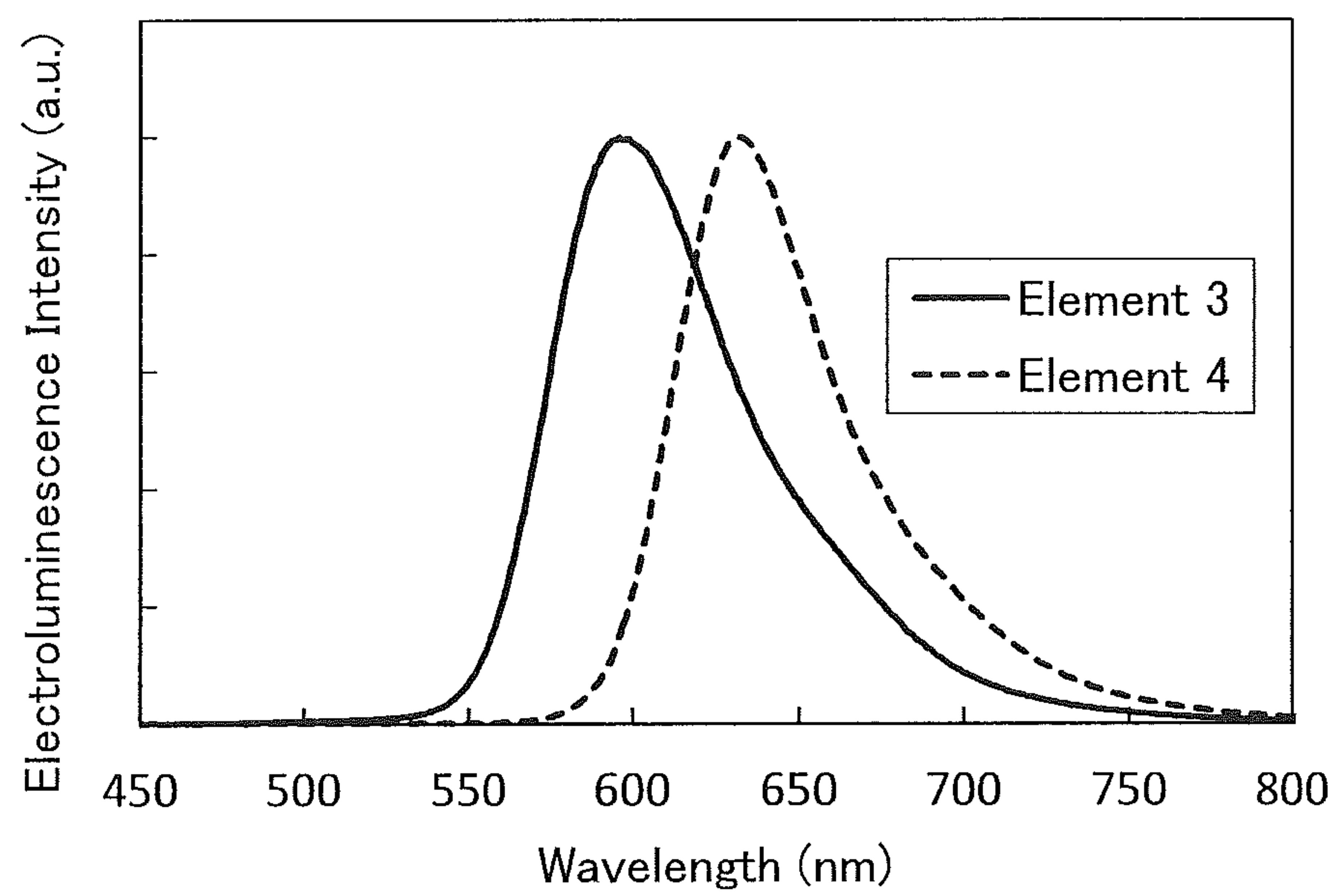


FIG. 51

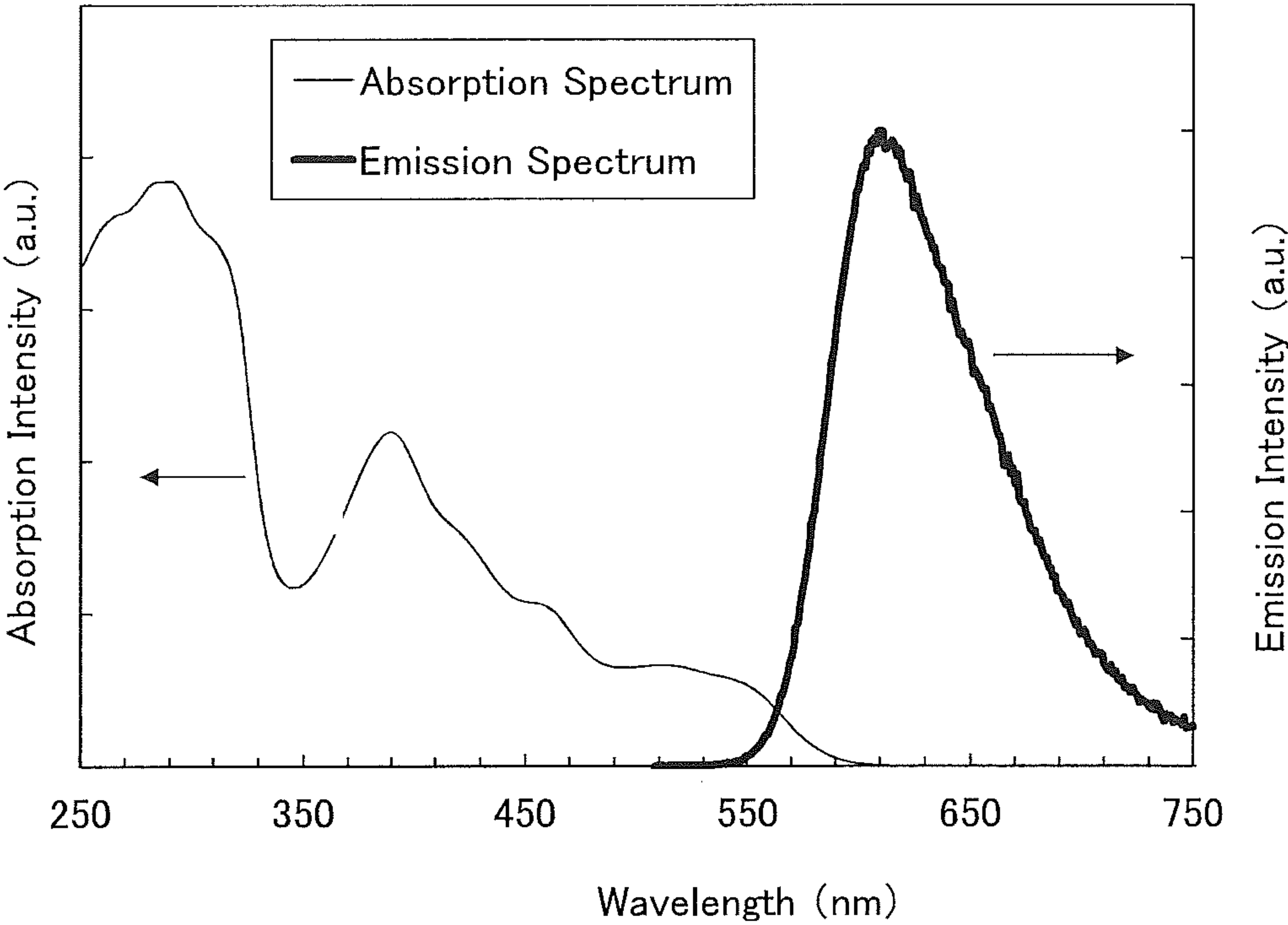


FIG. 52

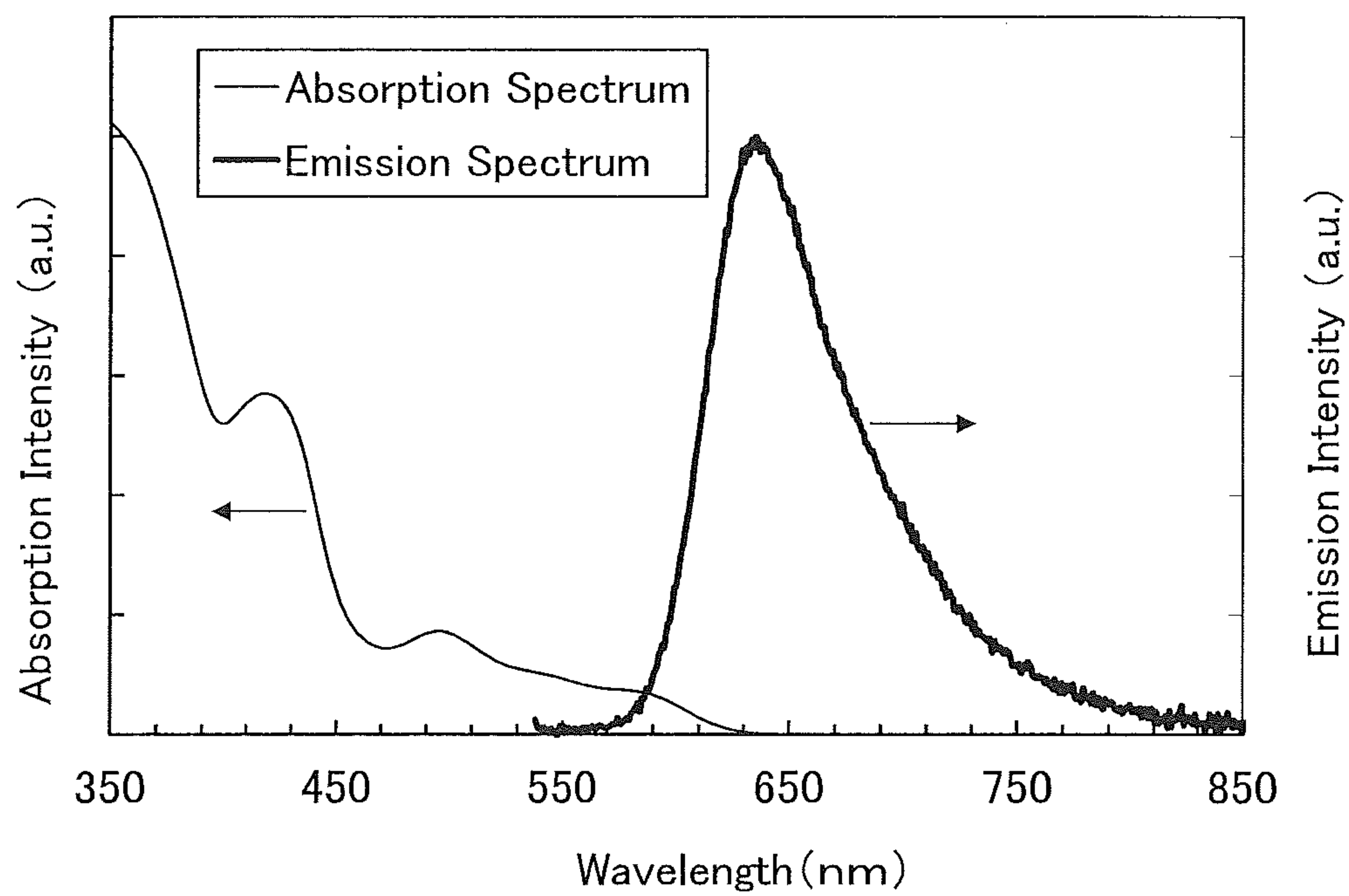


FIG. 53

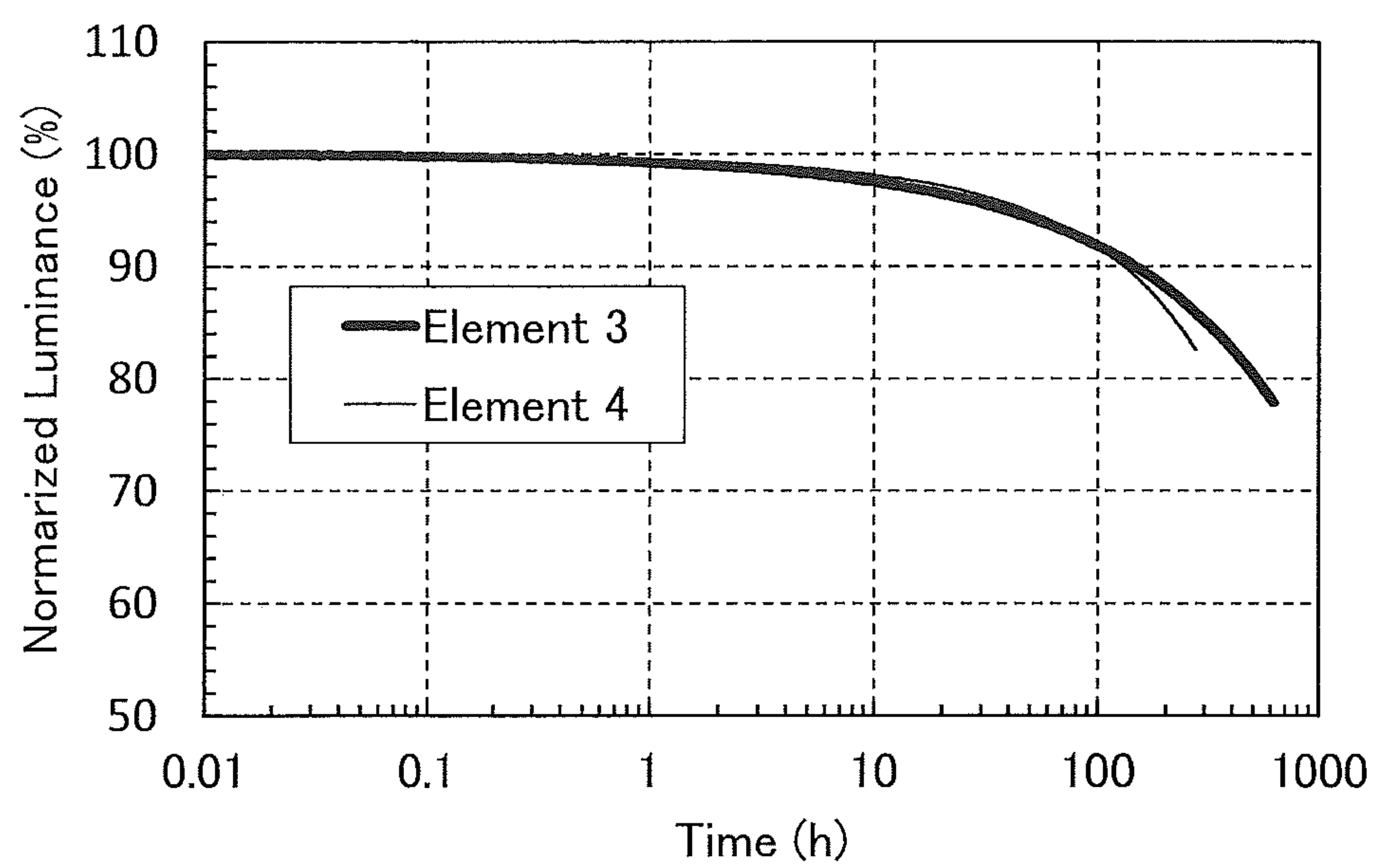


FIG. 54

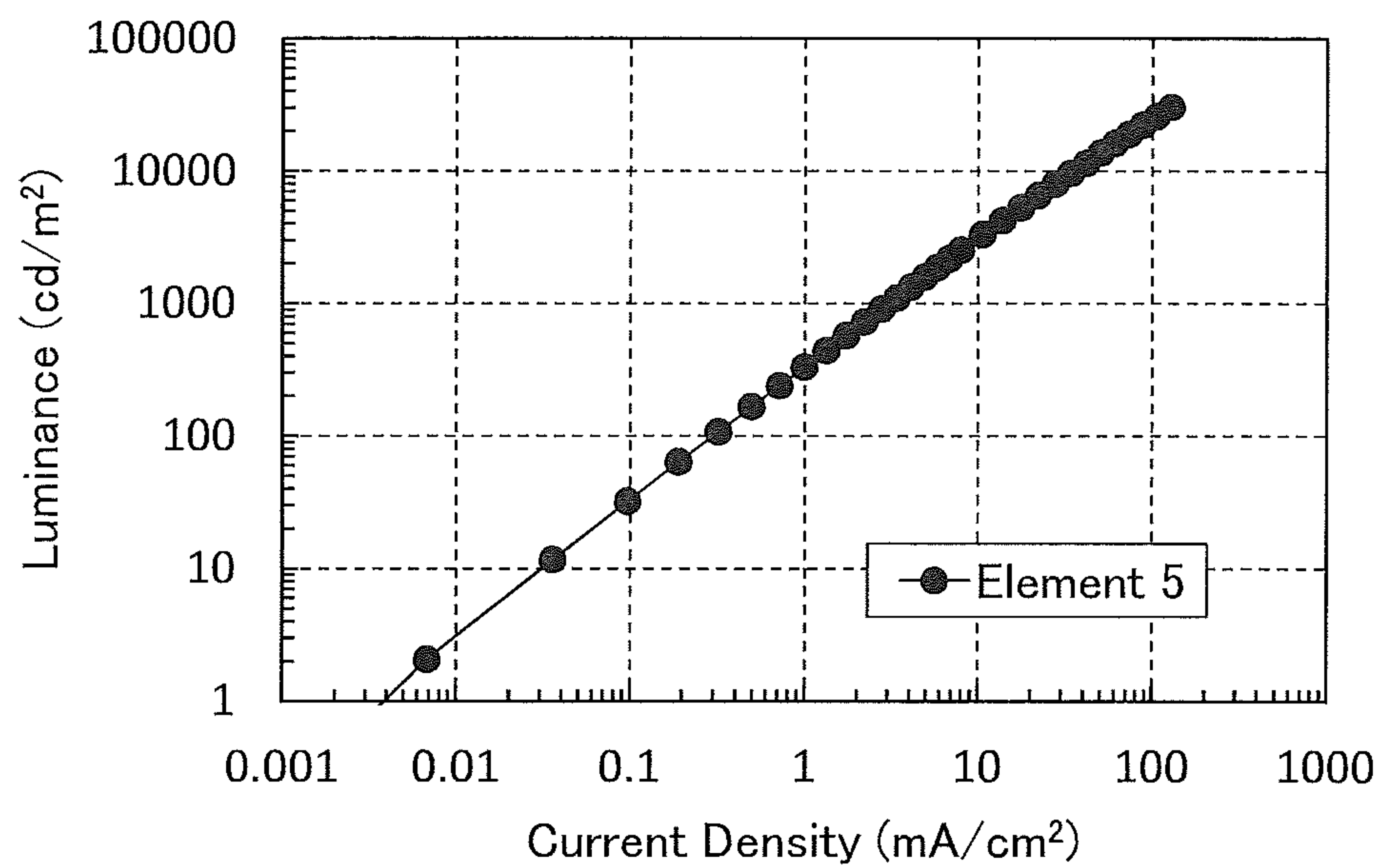


FIG. 55

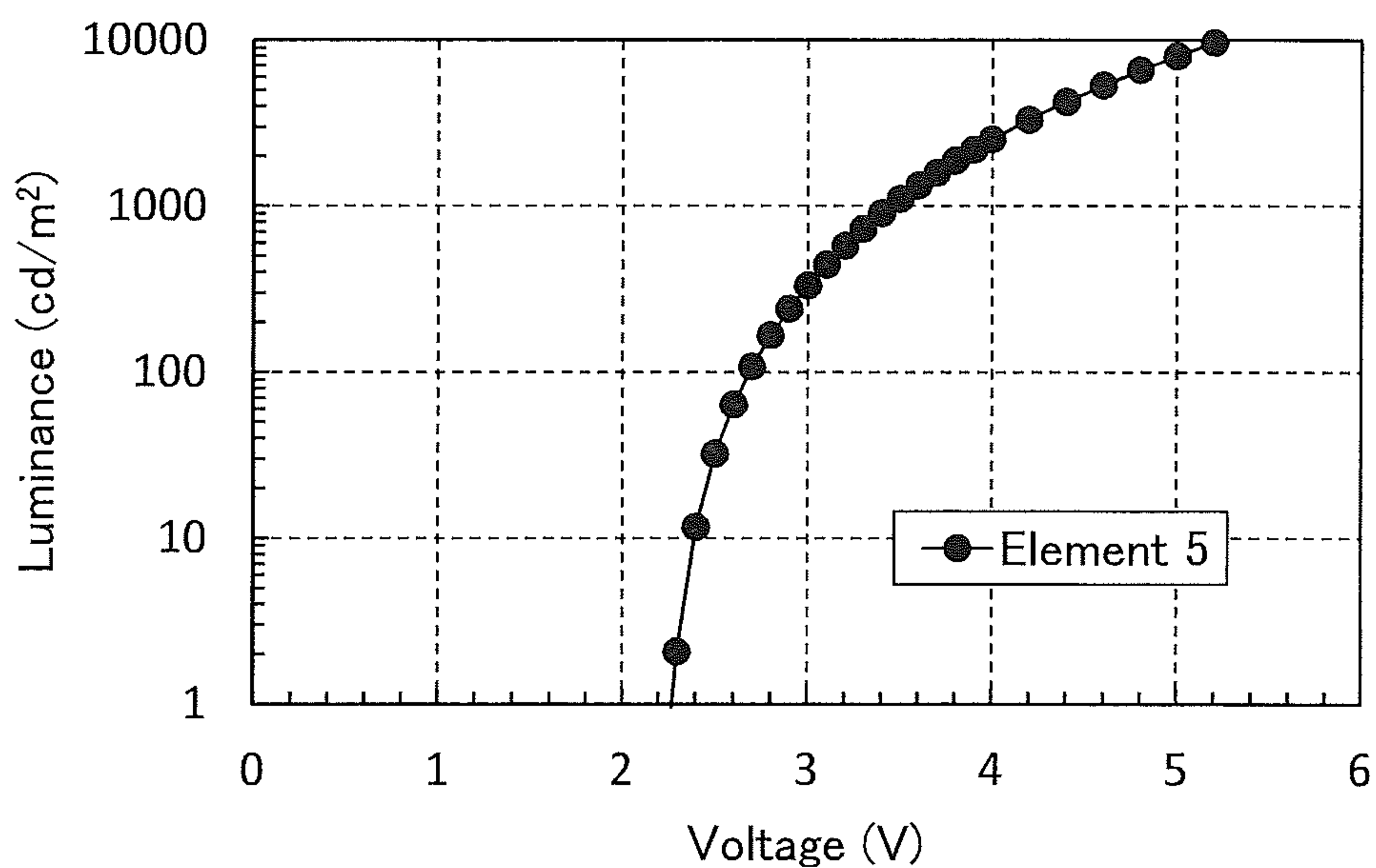


FIG. 56

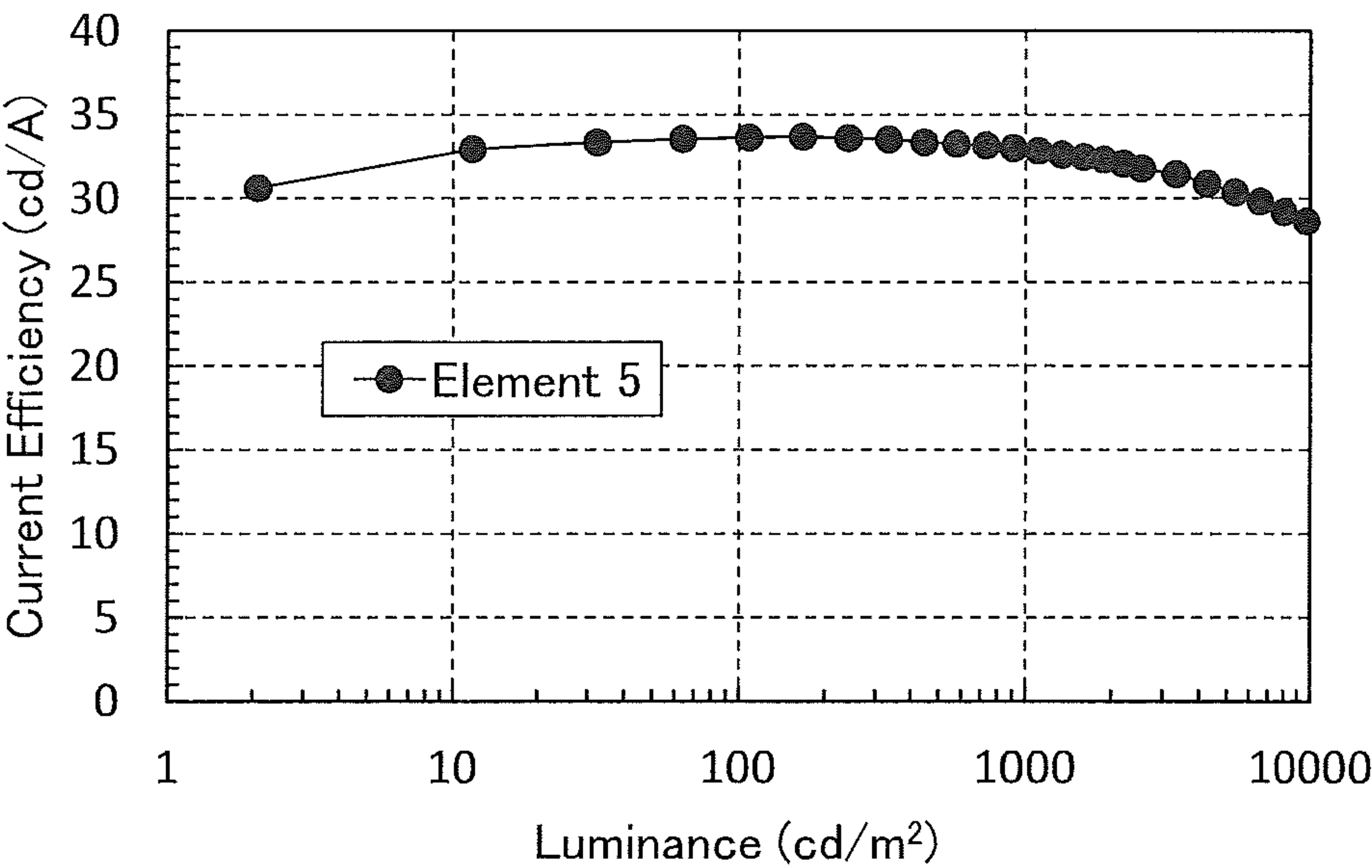


FIG. 57

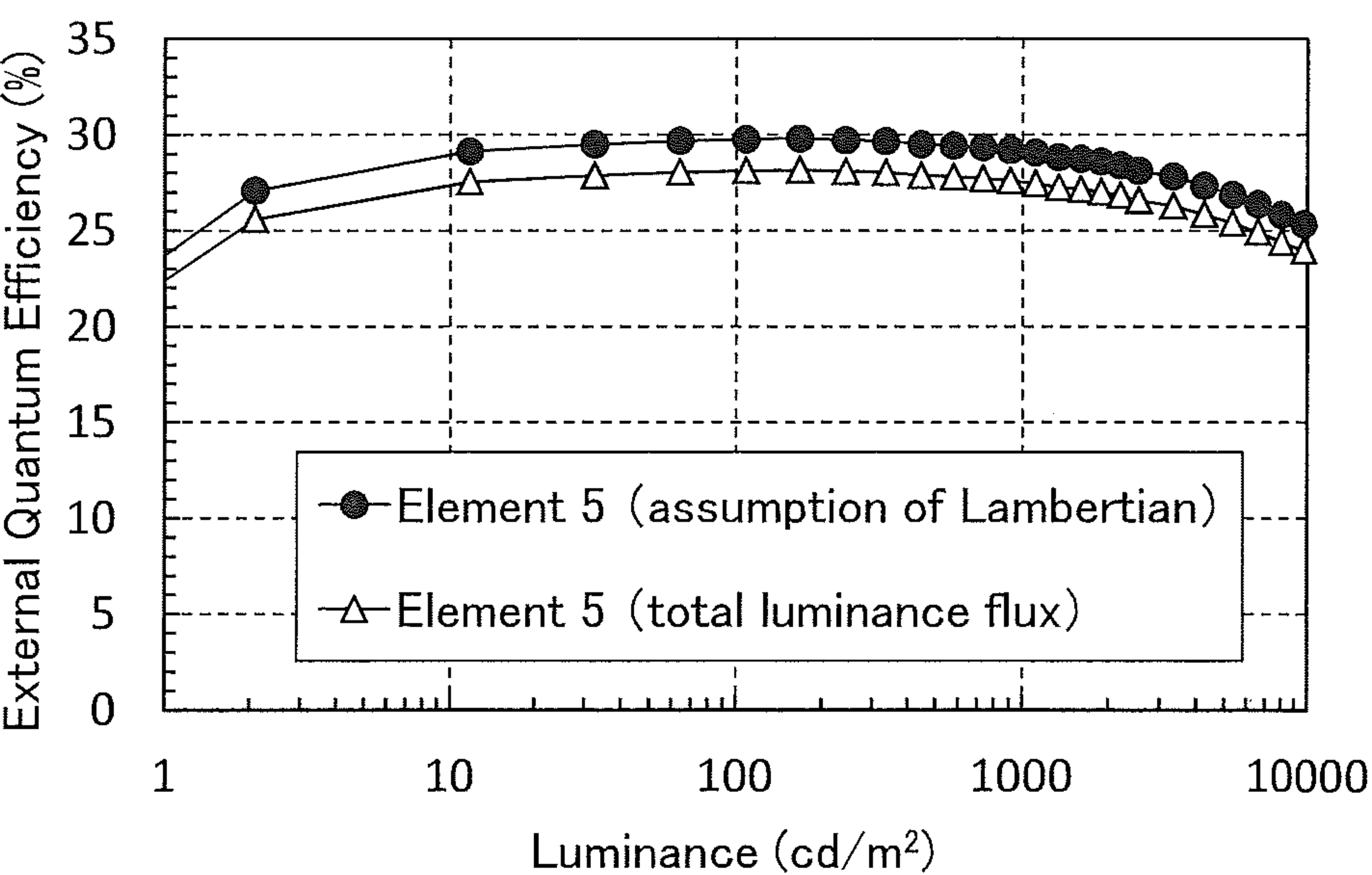


FIG. 58

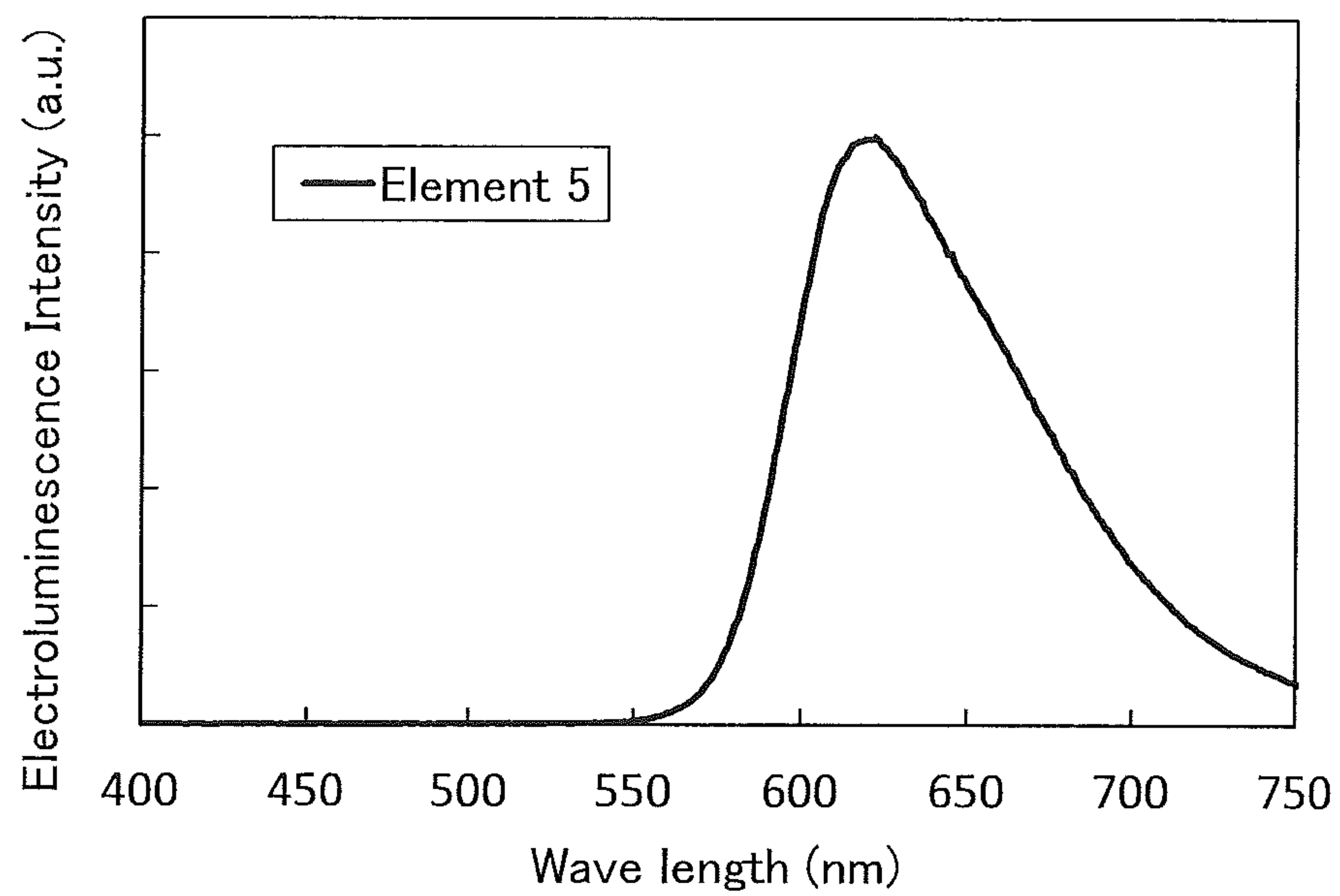


FIG. 59

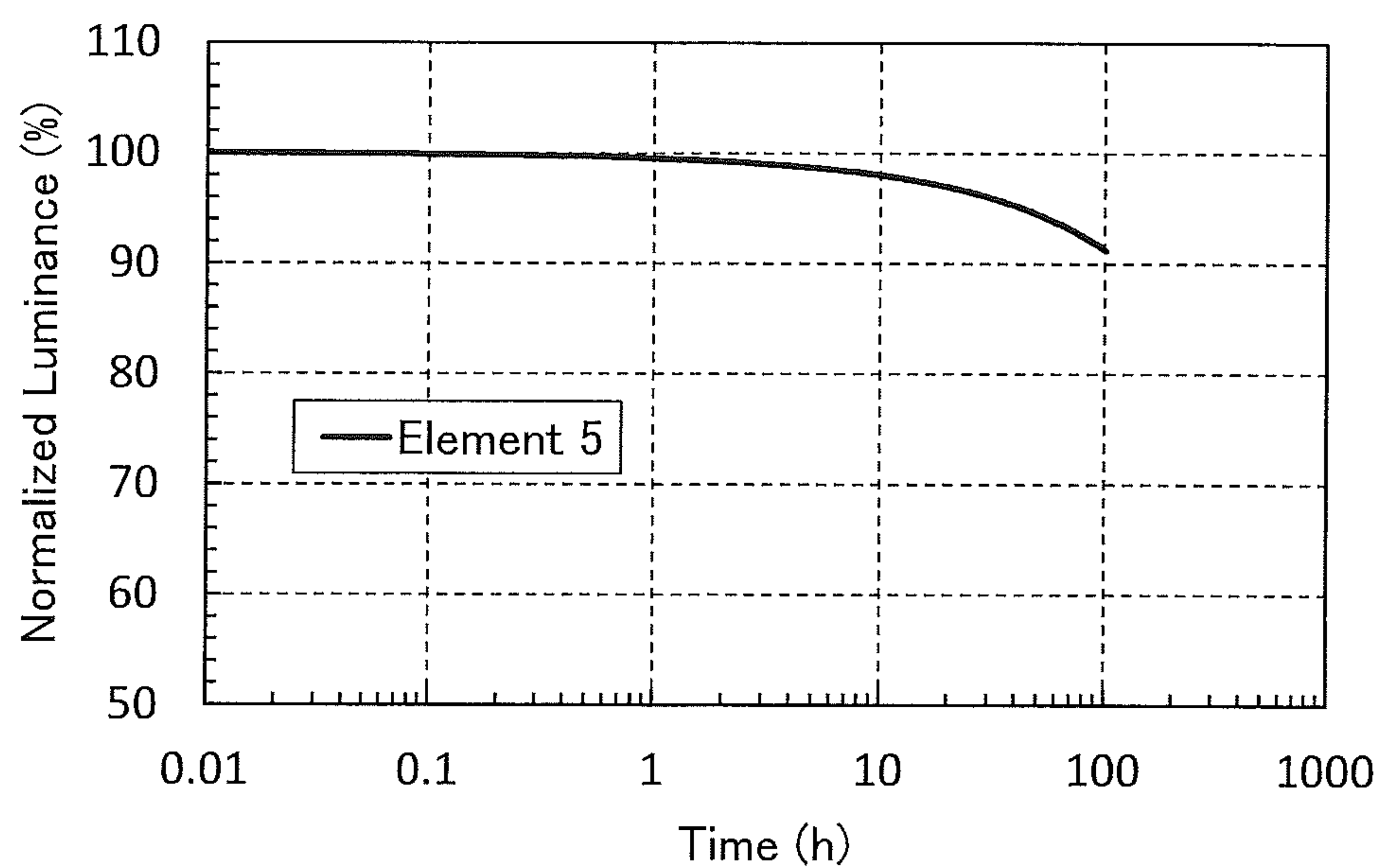


FIG. 60

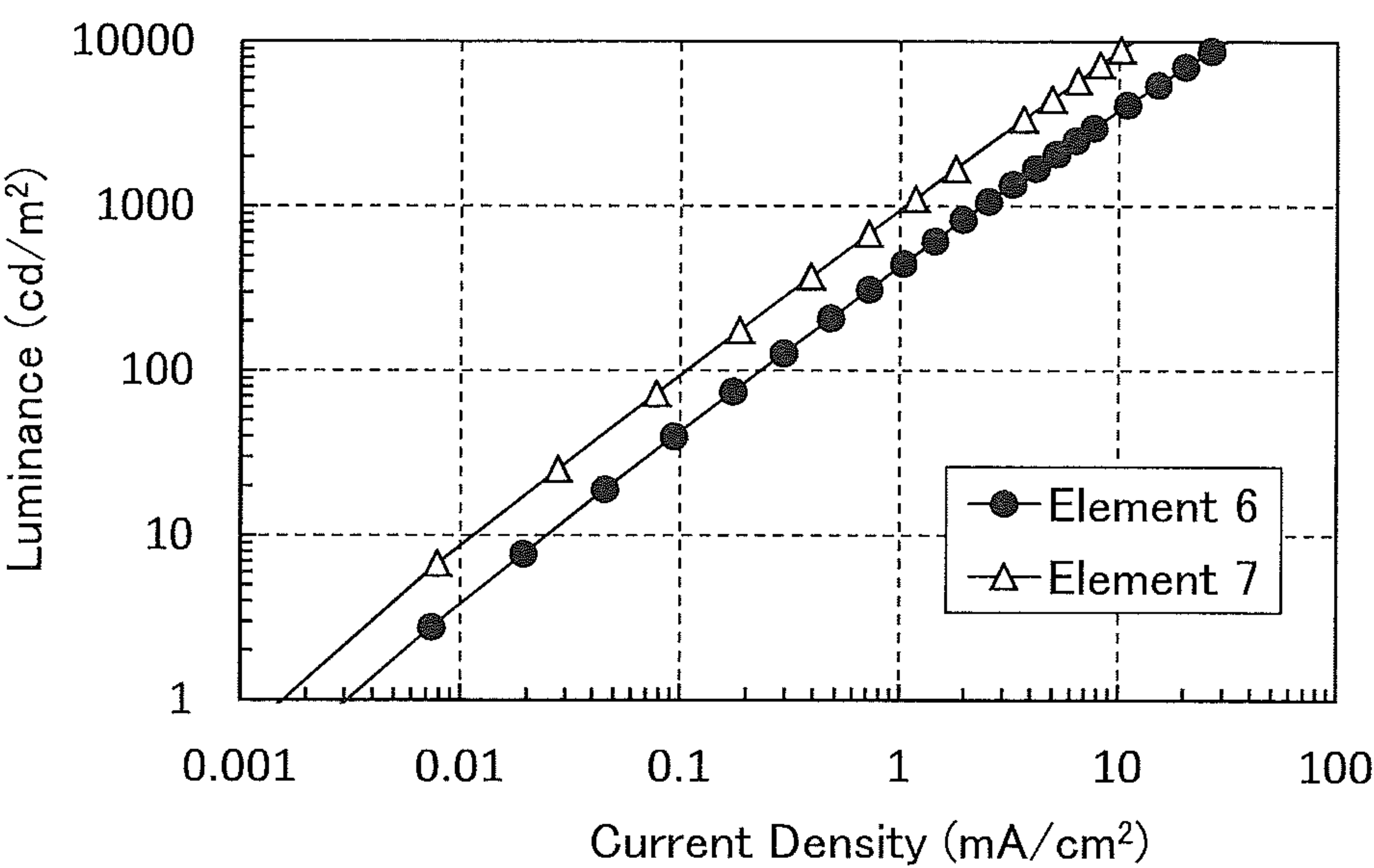


FIG. 61

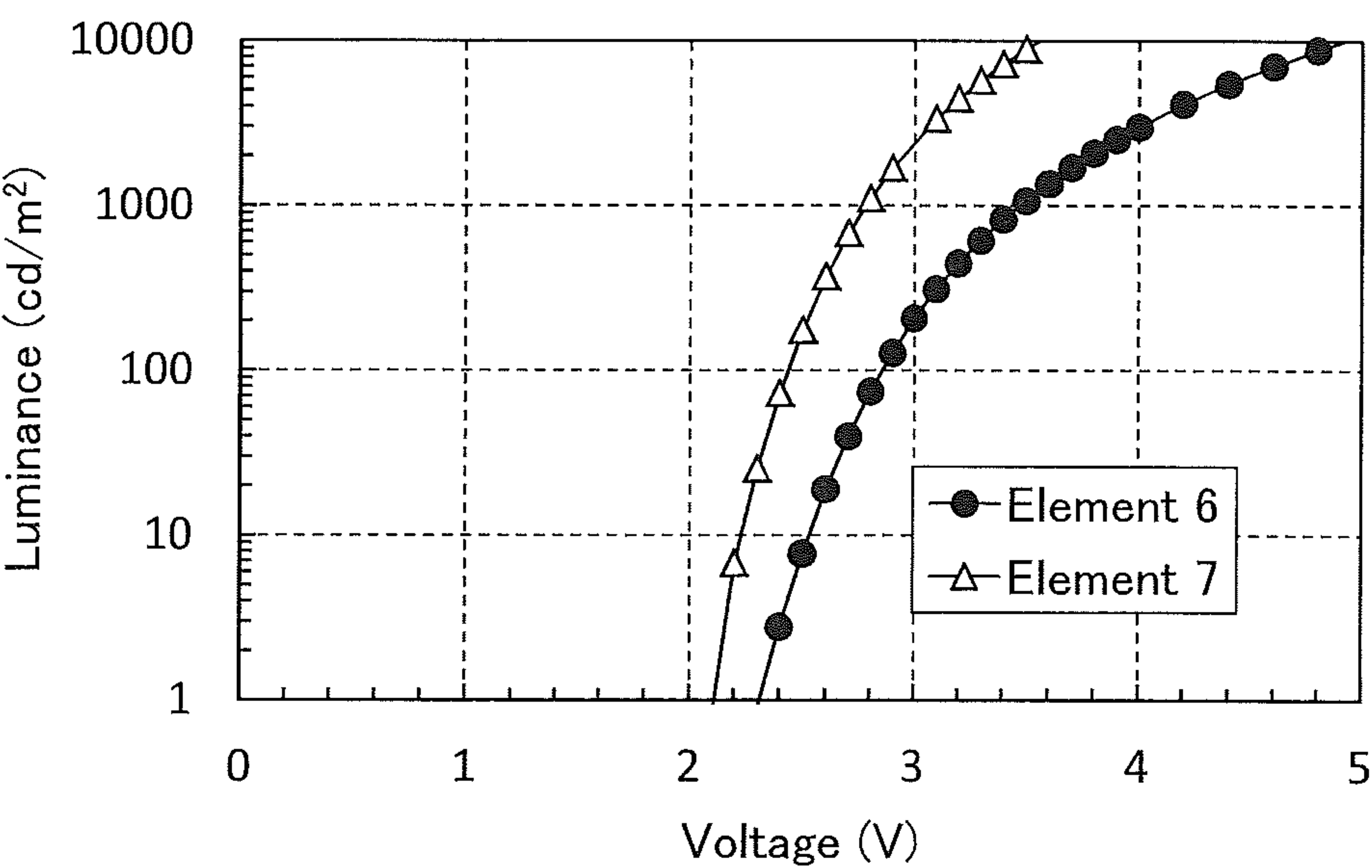


FIG. 62

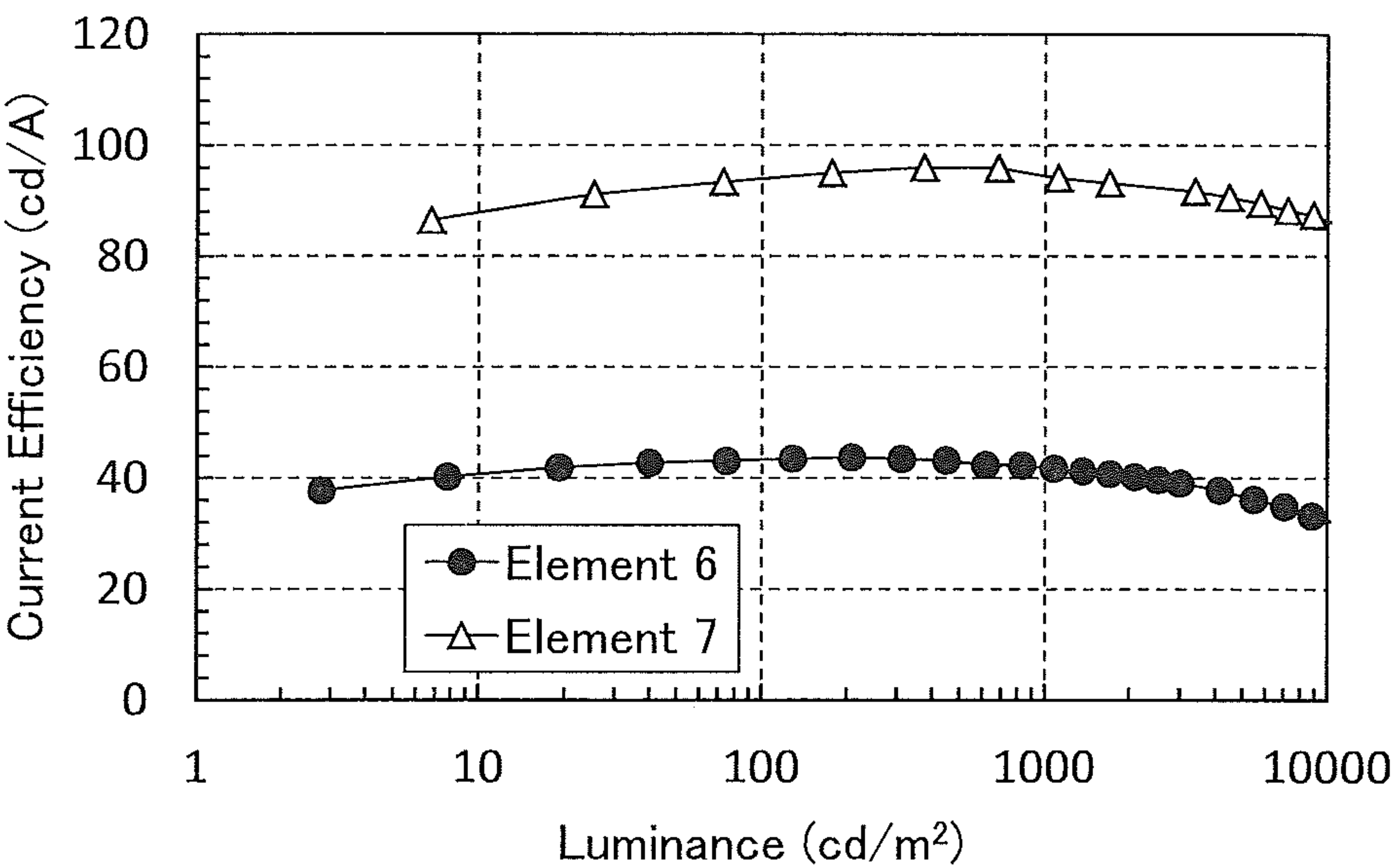


FIG. 63

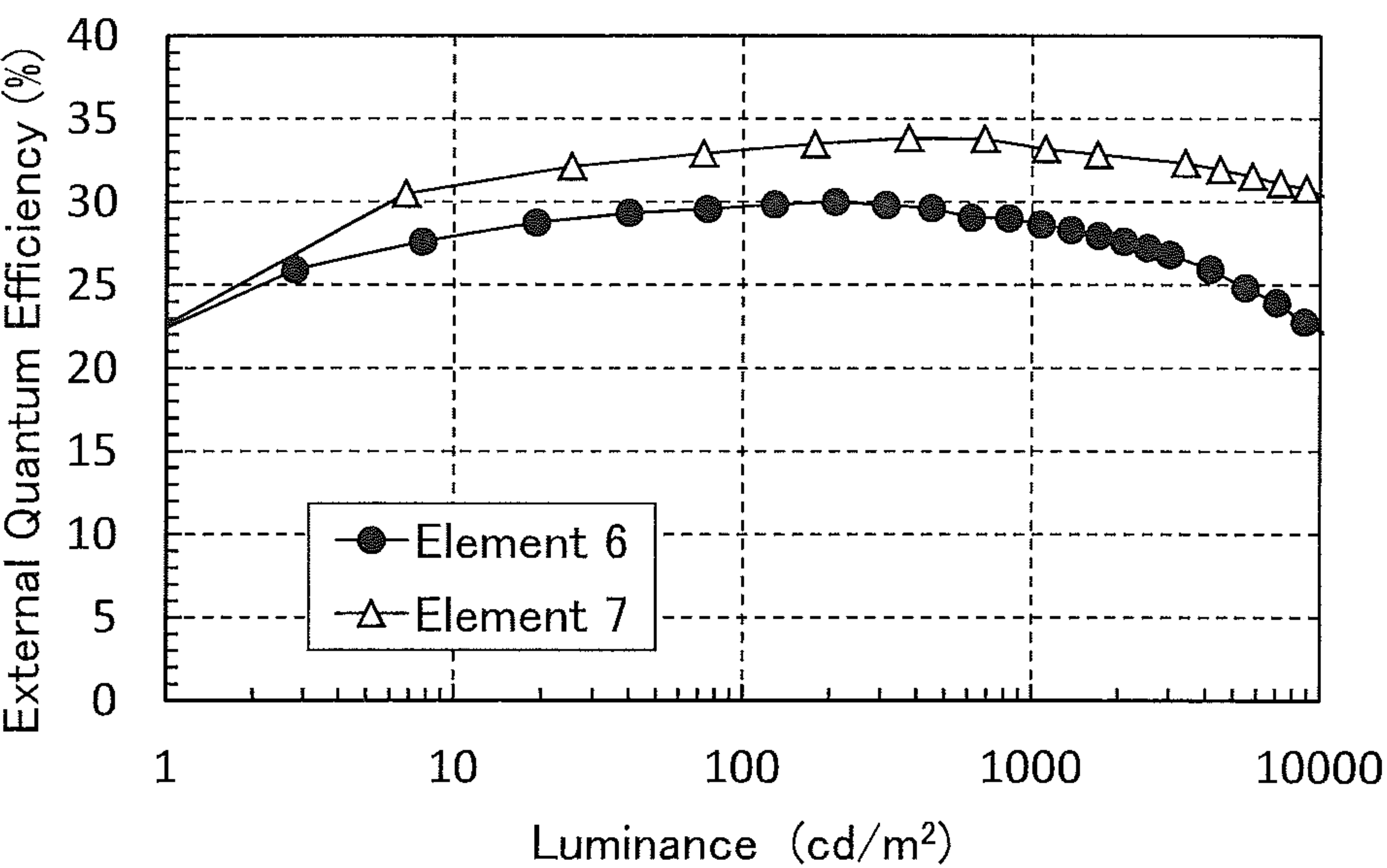


FIG. 64

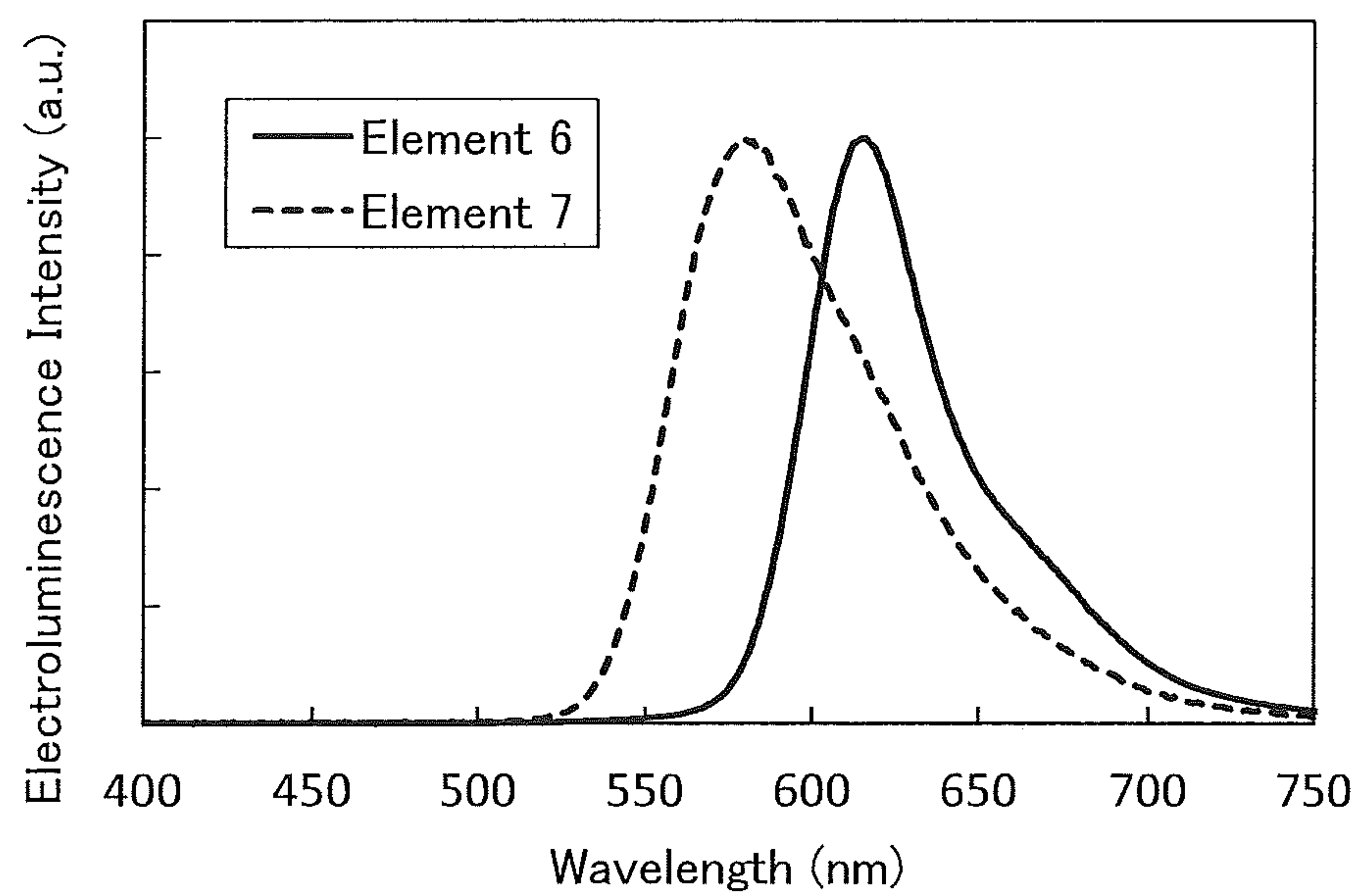


FIG. 65A

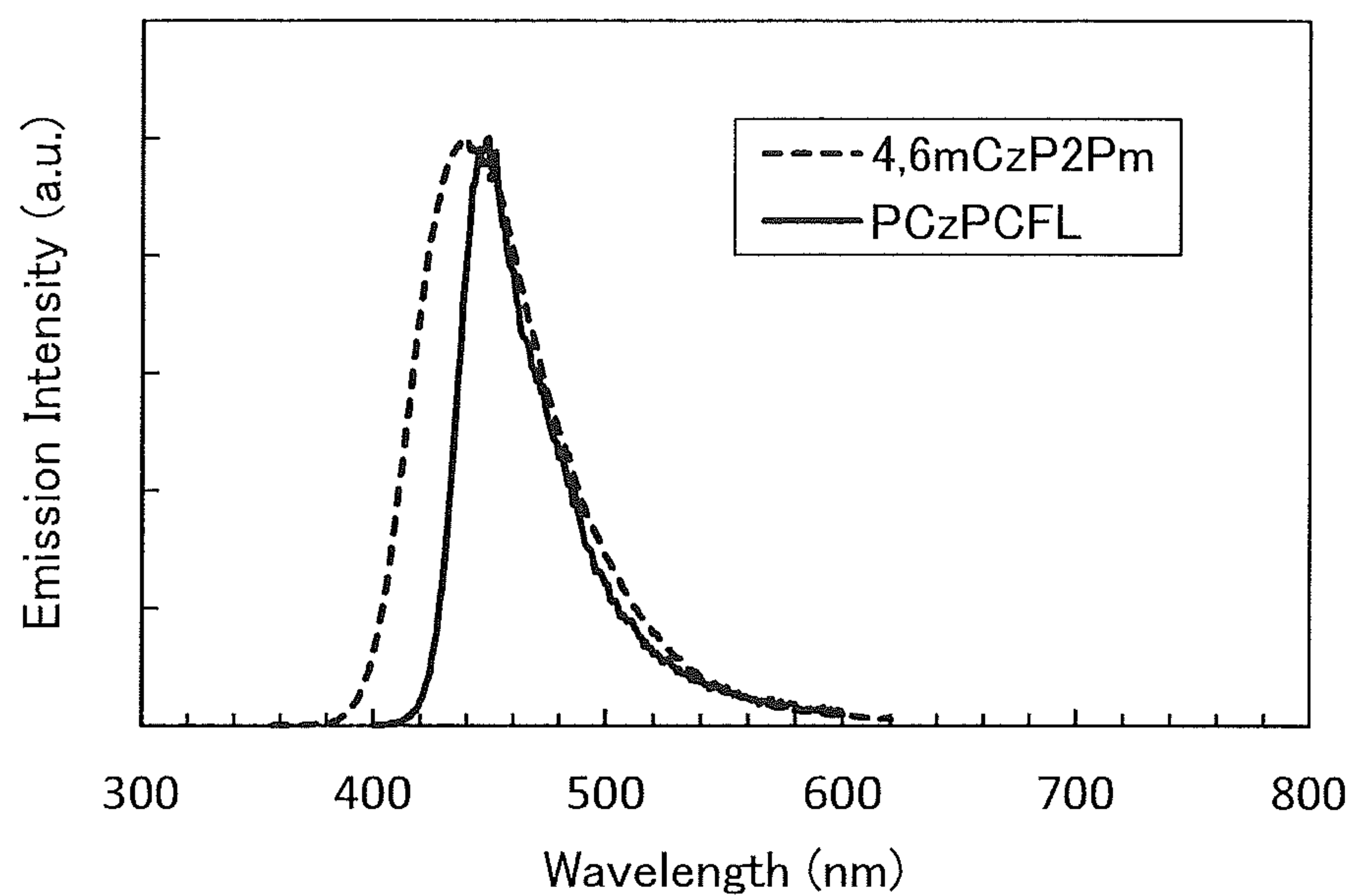


FIG. 65B

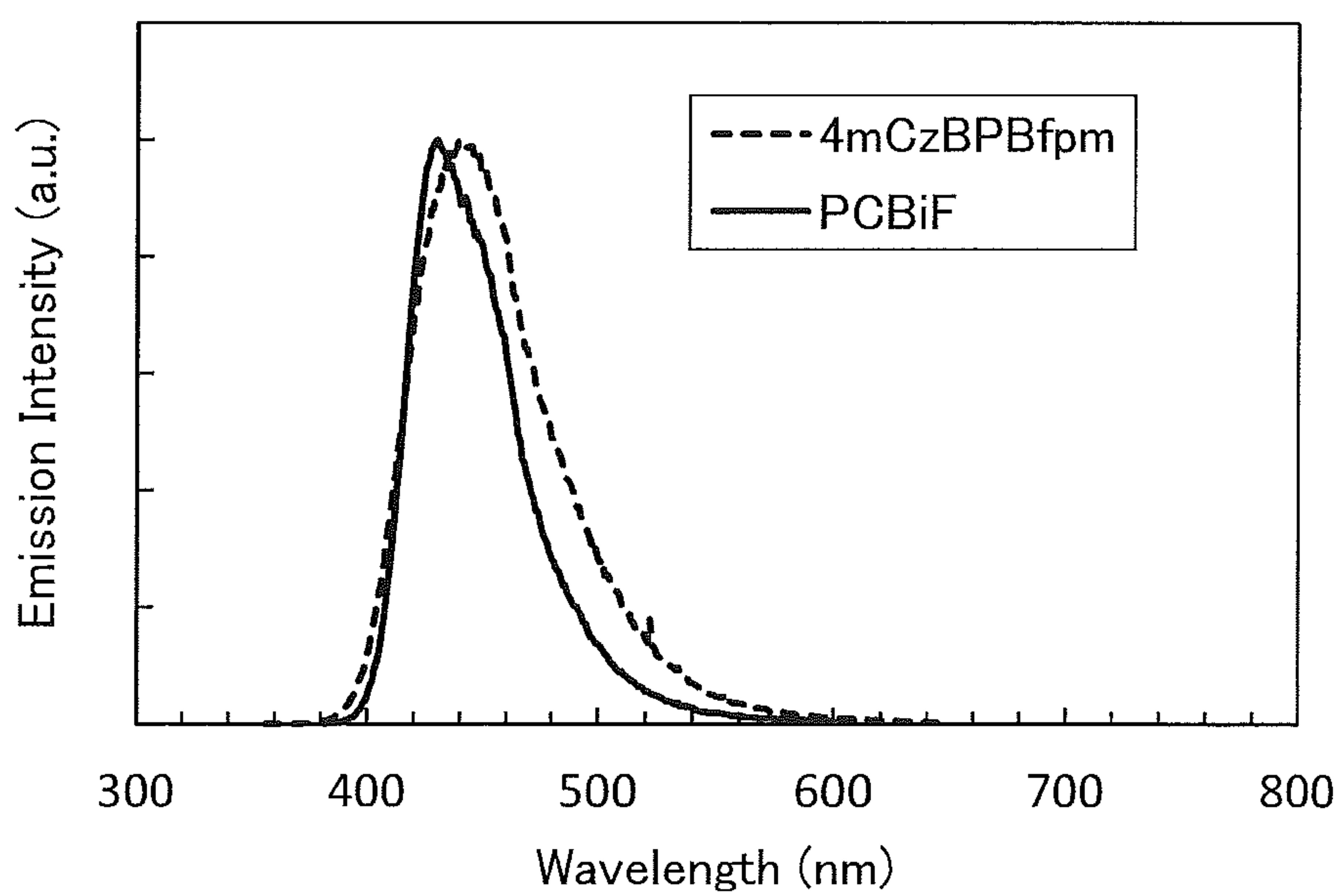


FIG. 66

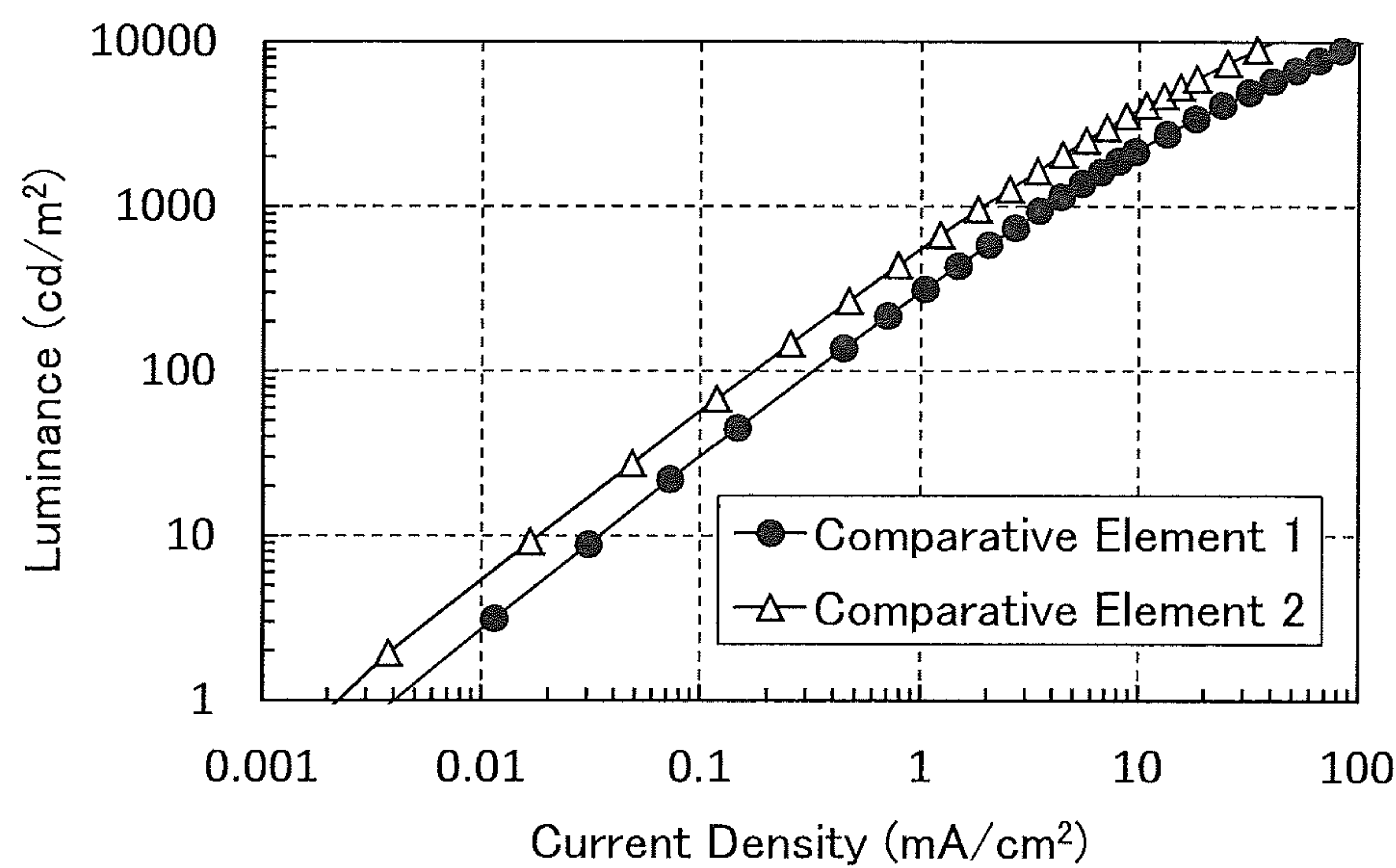


FIG. 67

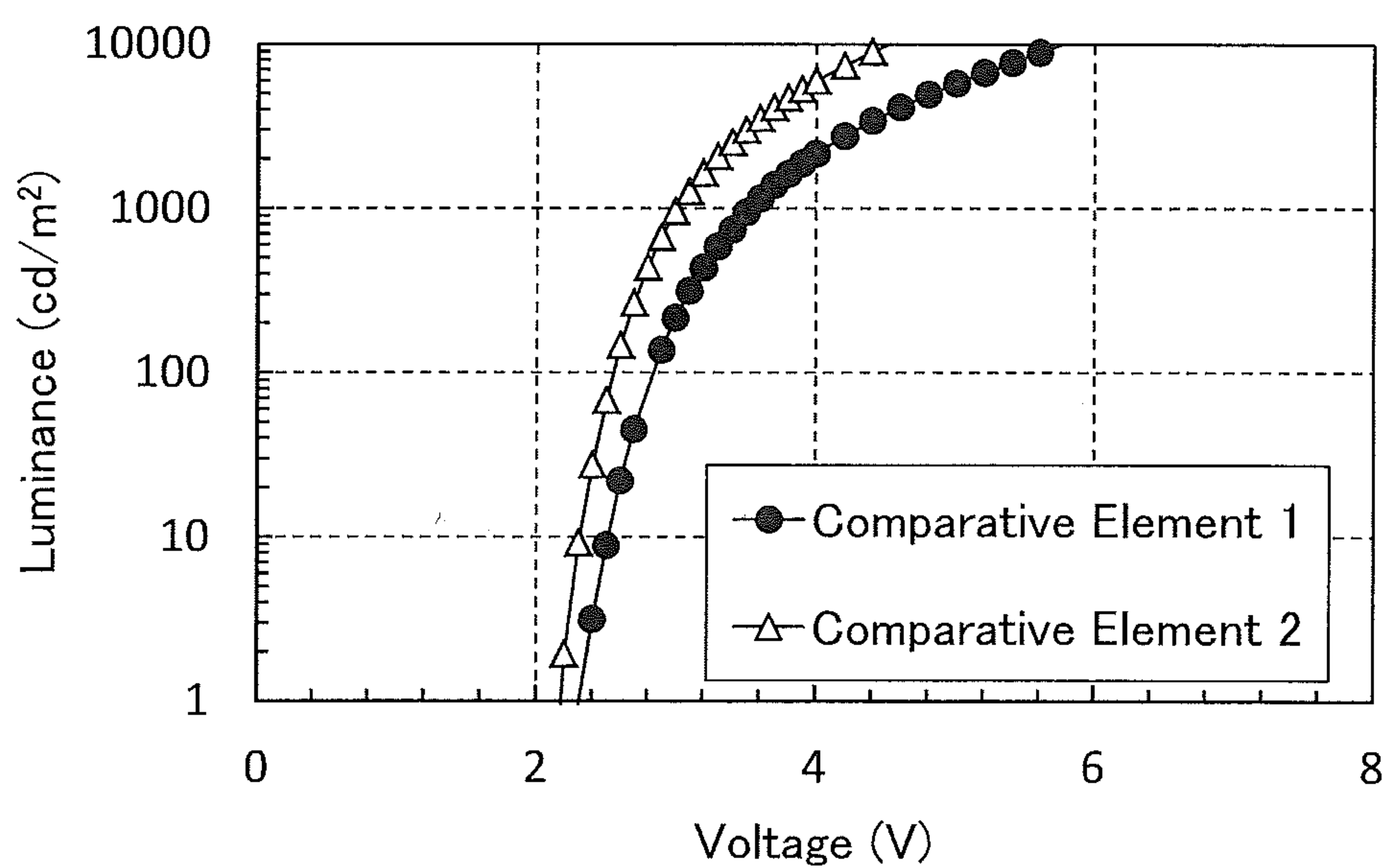


FIG. 68

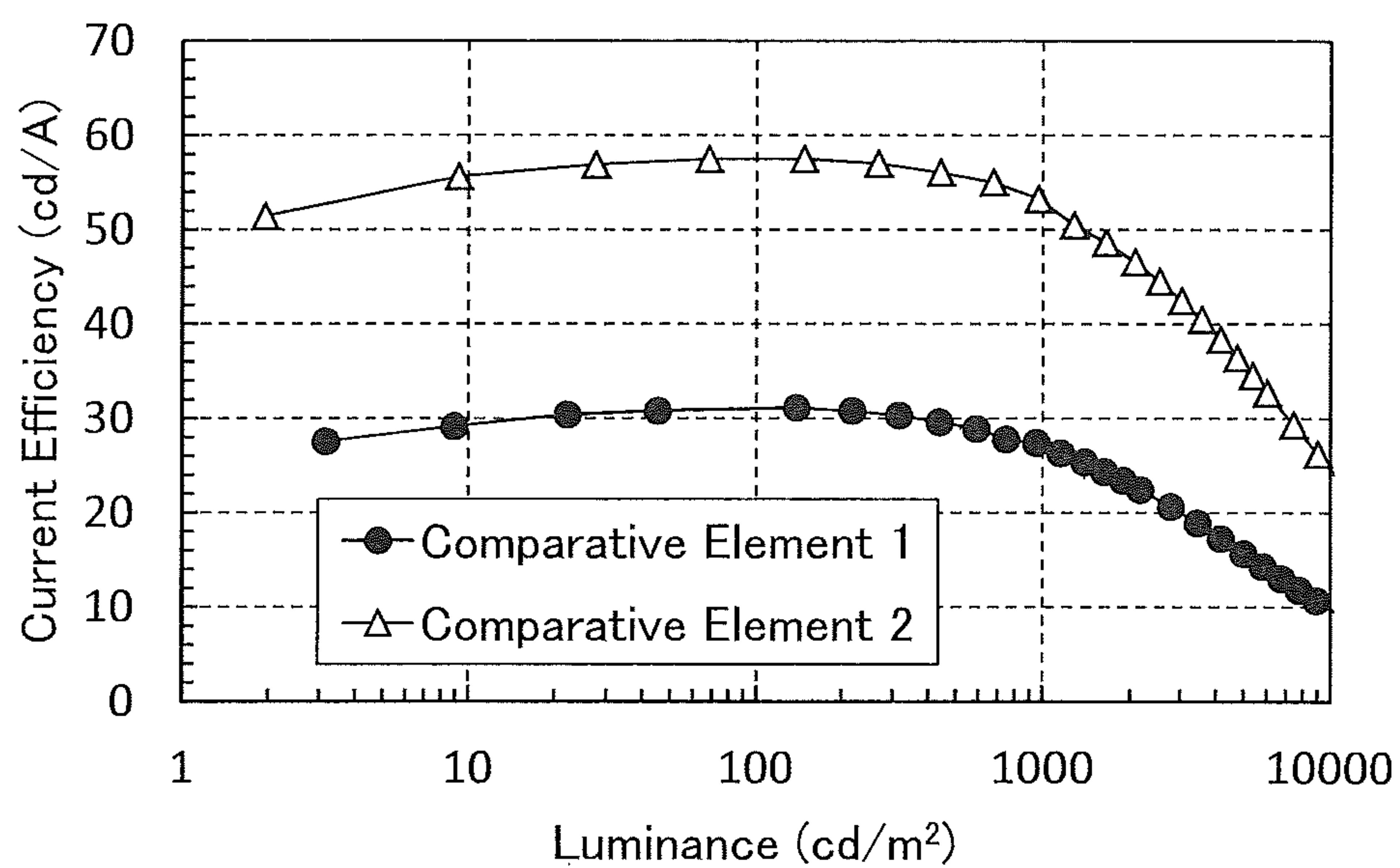


FIG. 69

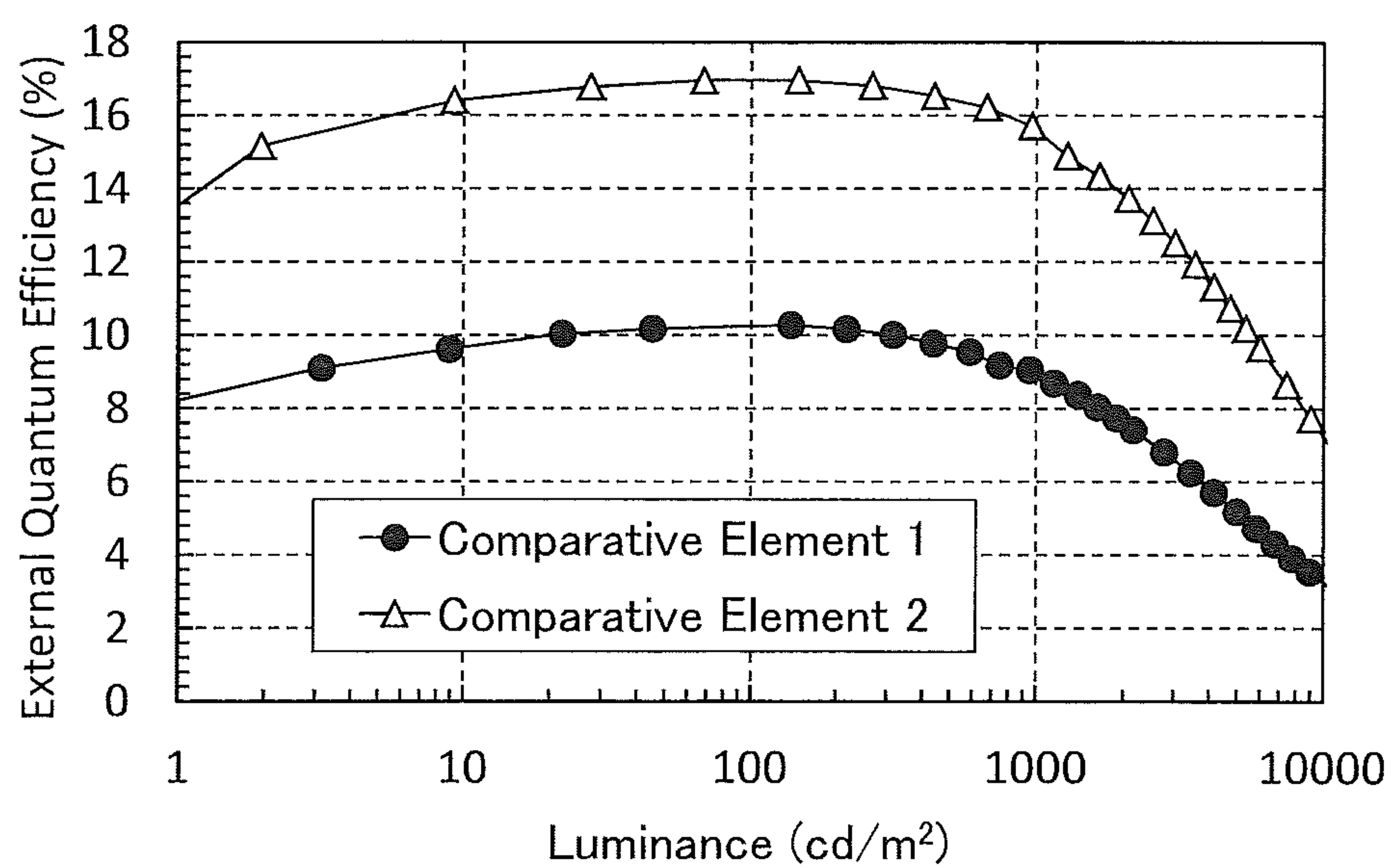


FIG. 70

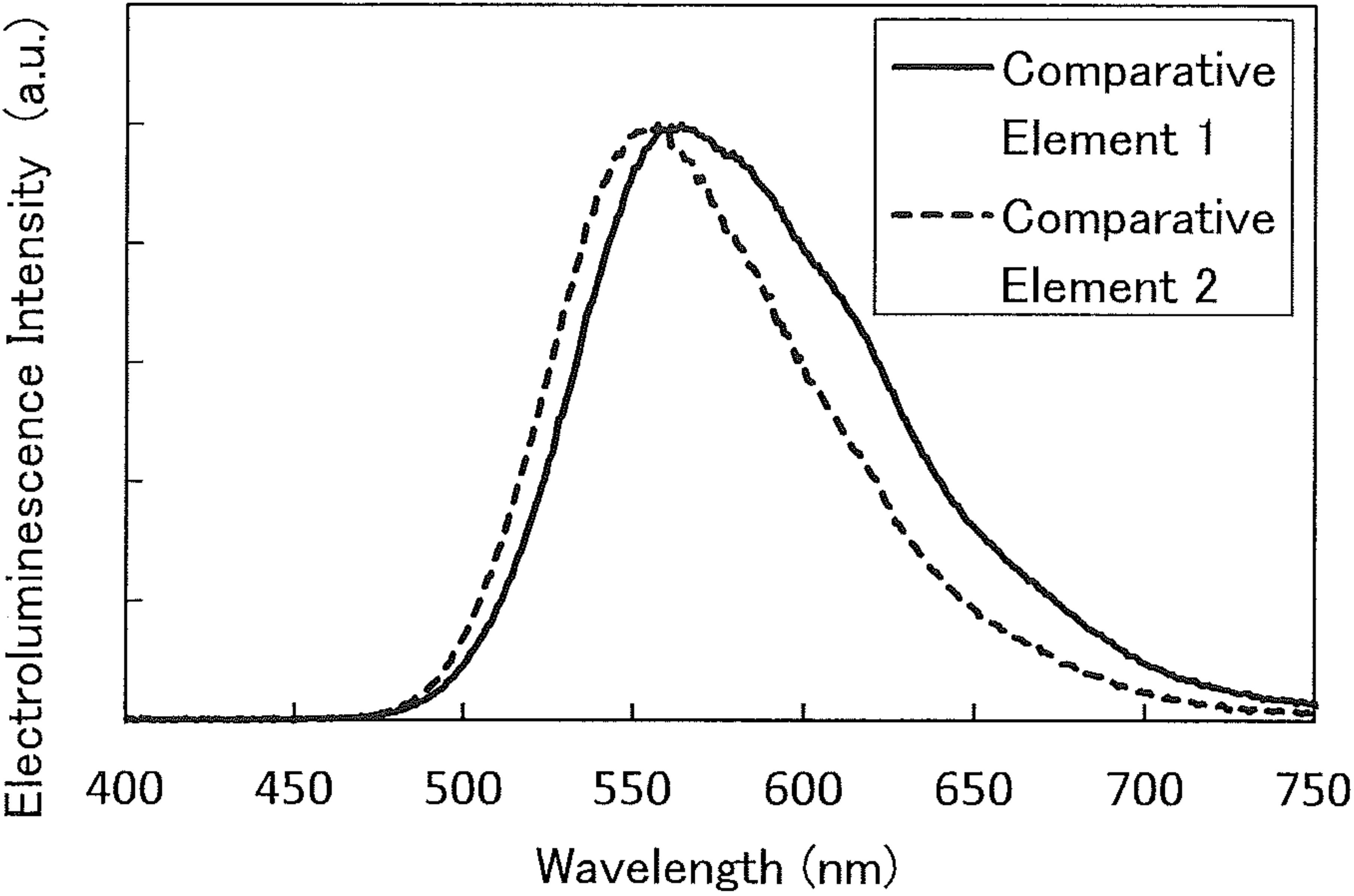


FIG. 71

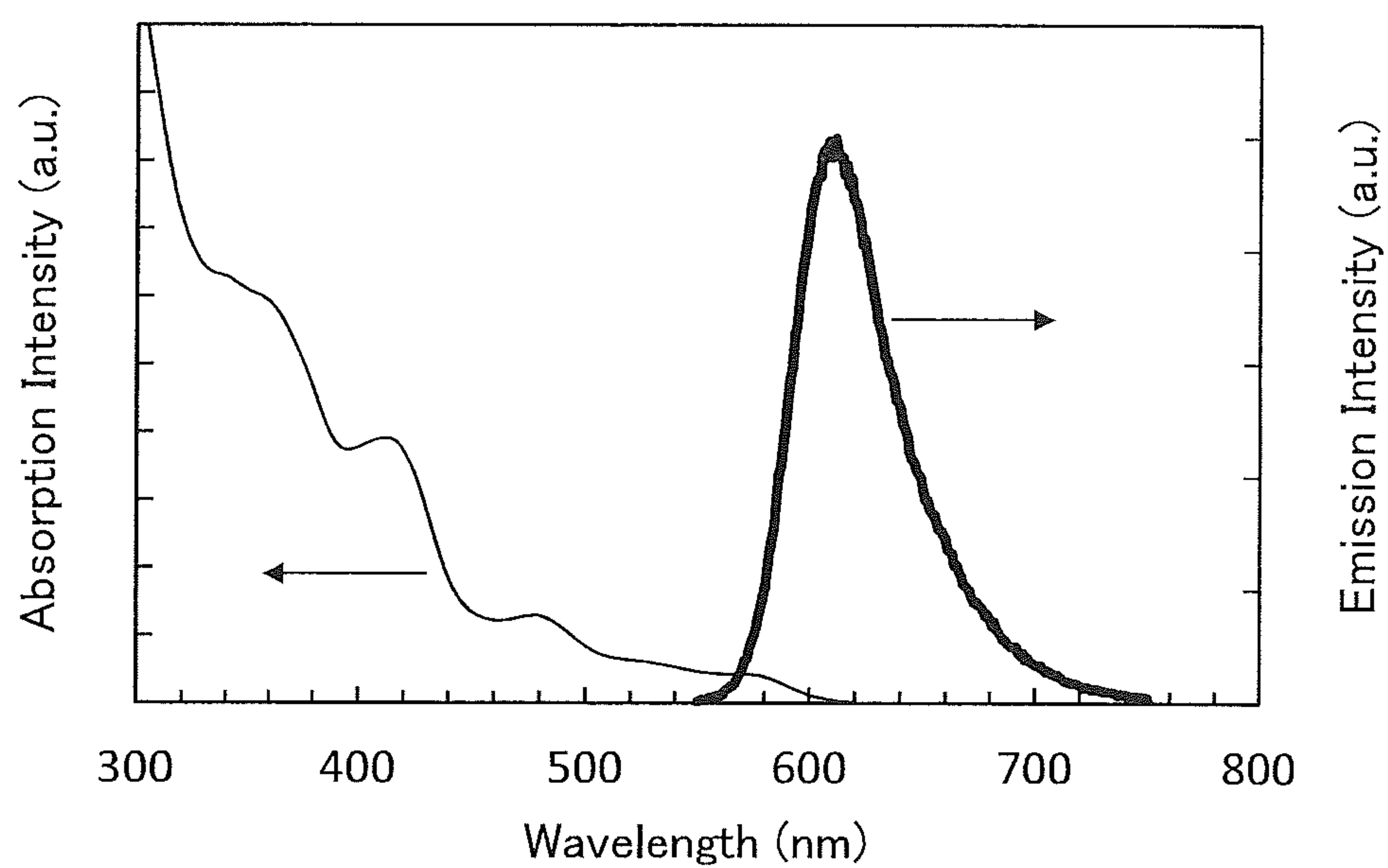


FIG. 72

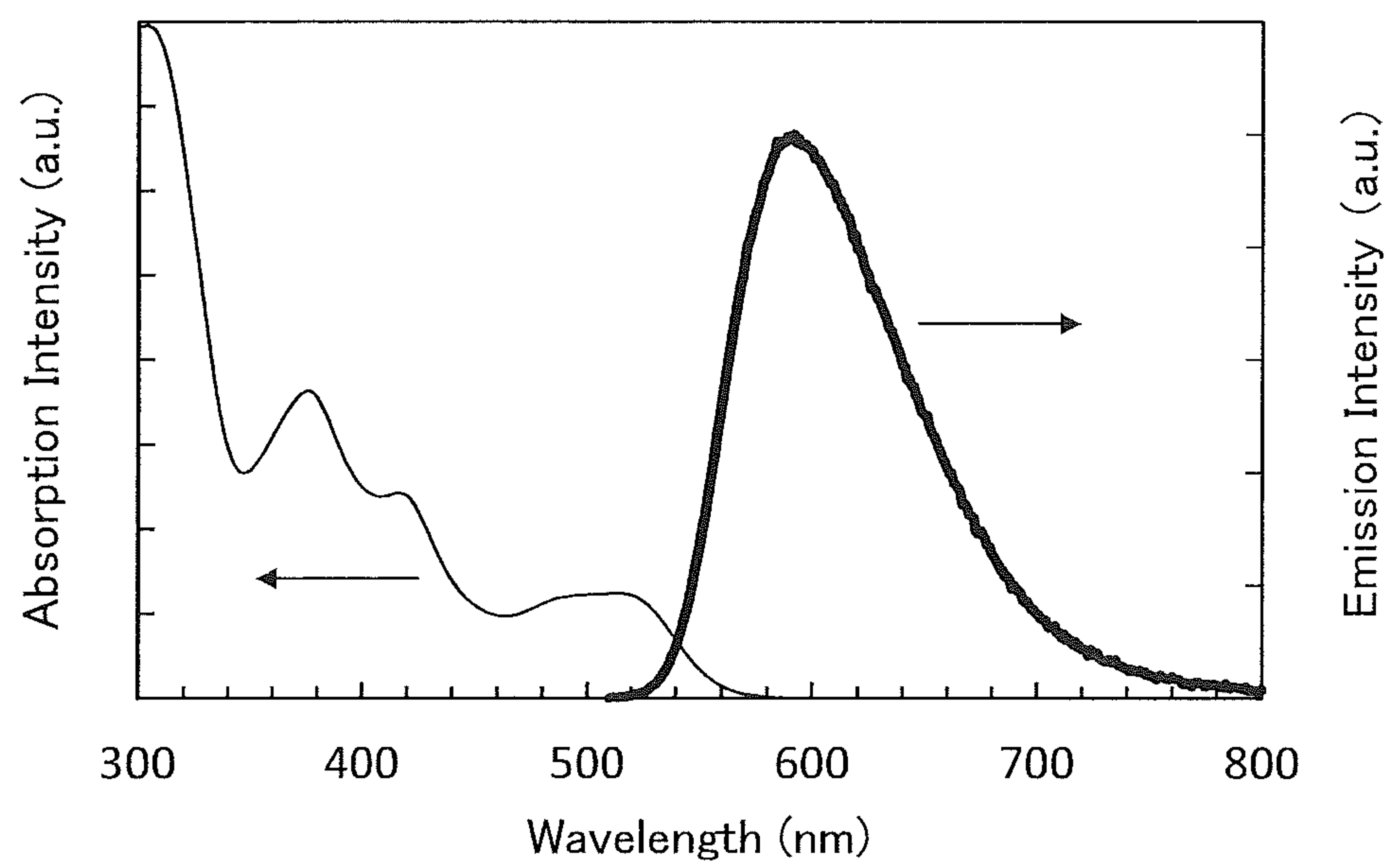


FIG. 73

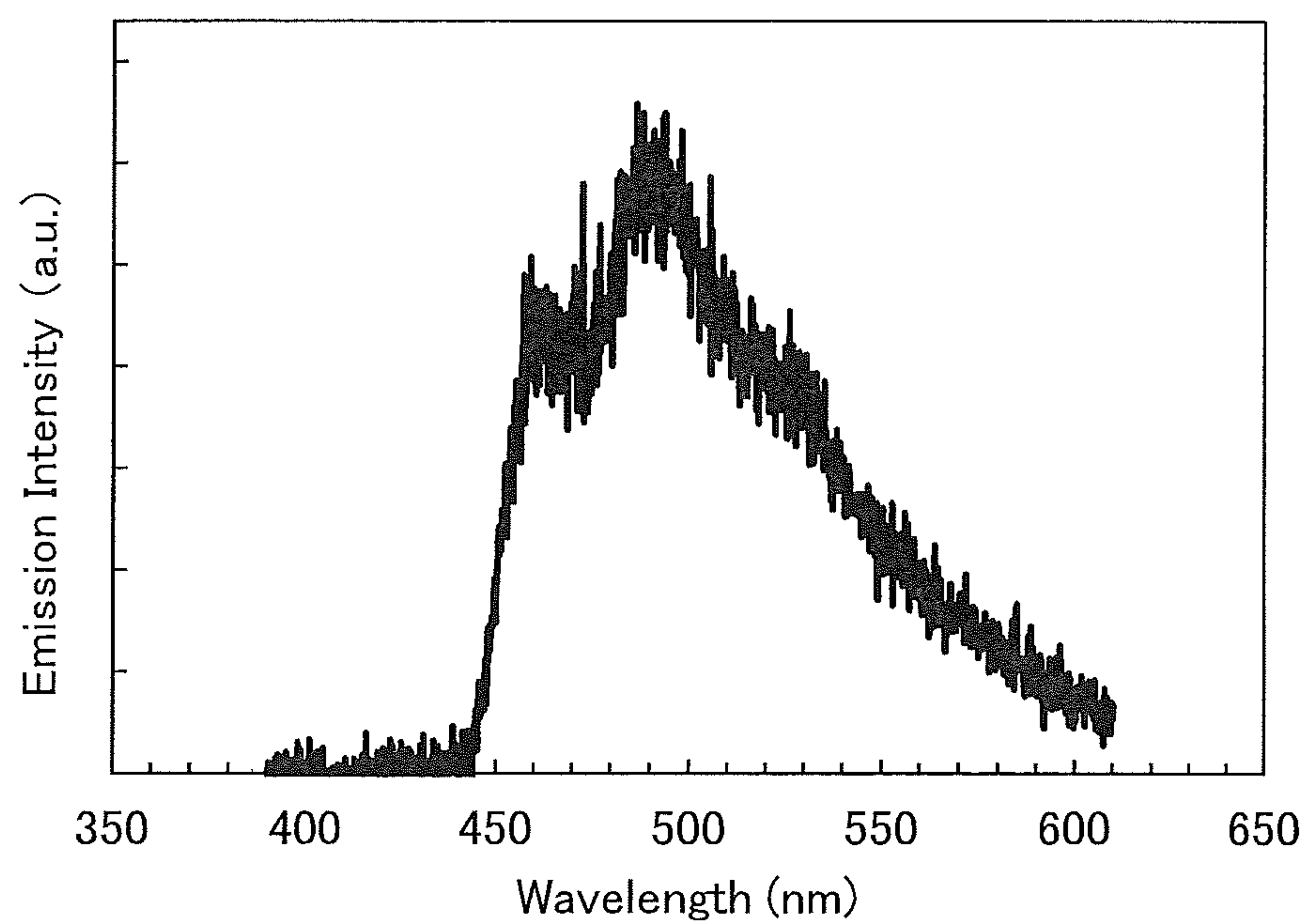


FIG. 74

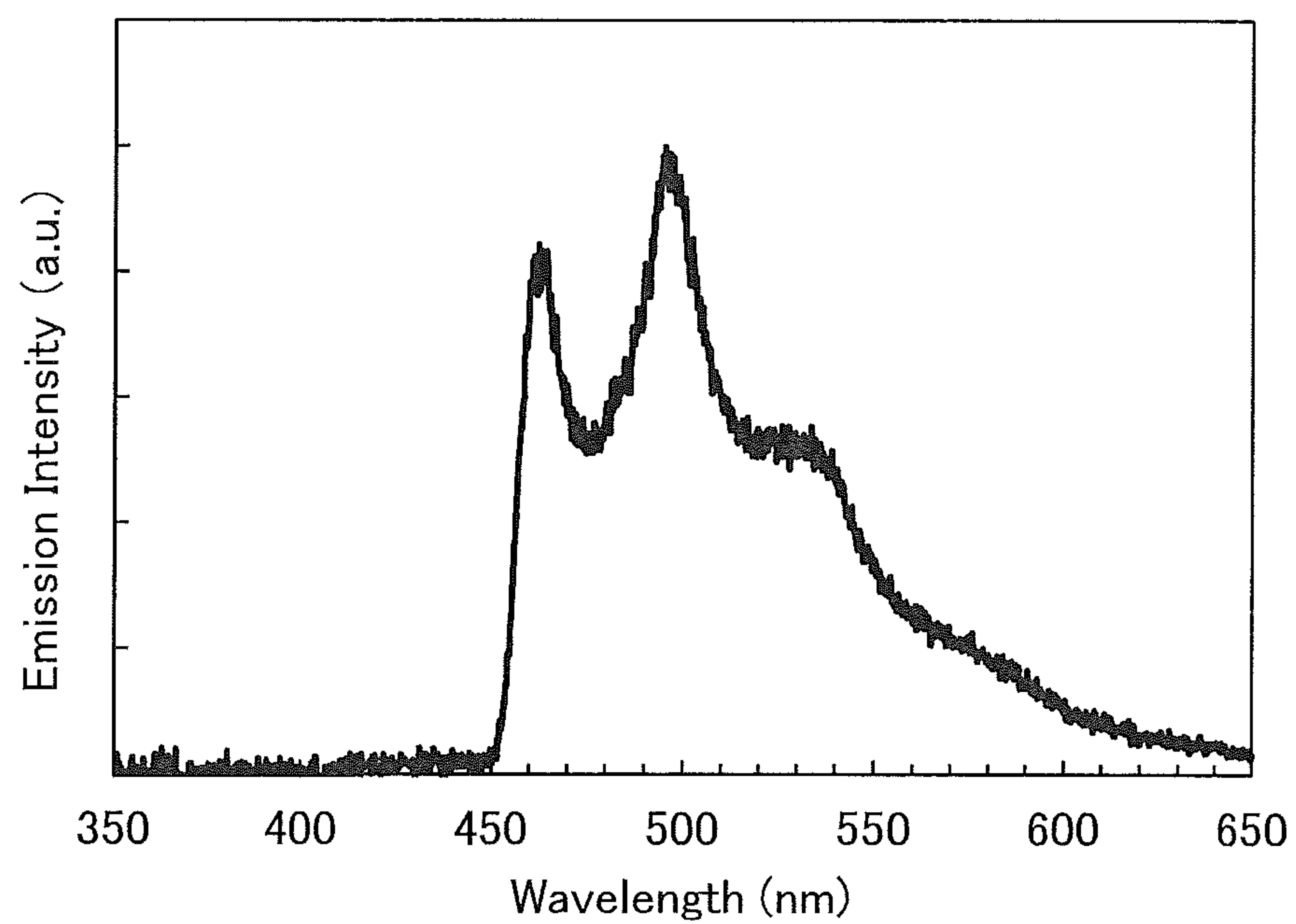


FIG. 75

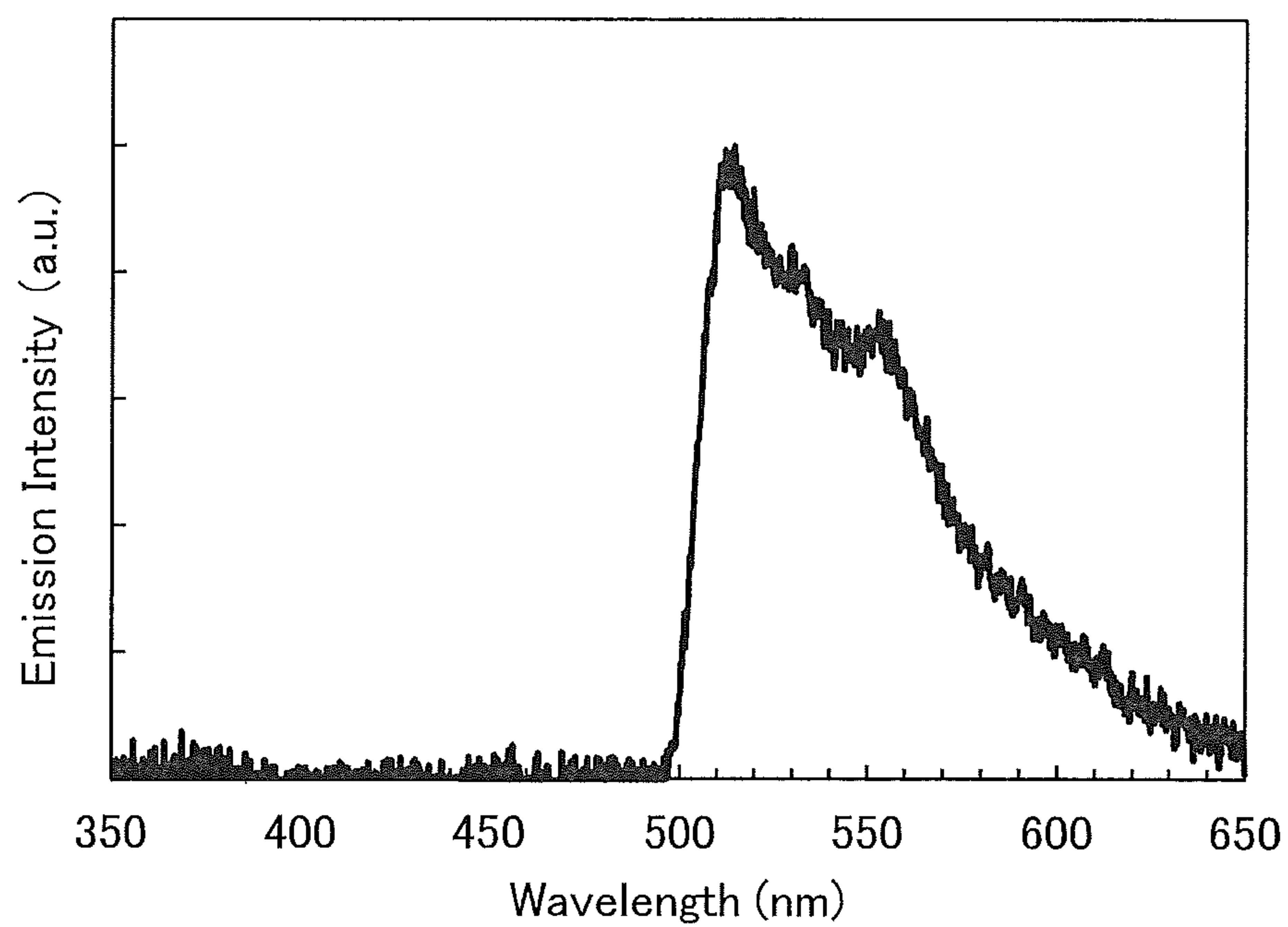


FIG. 76

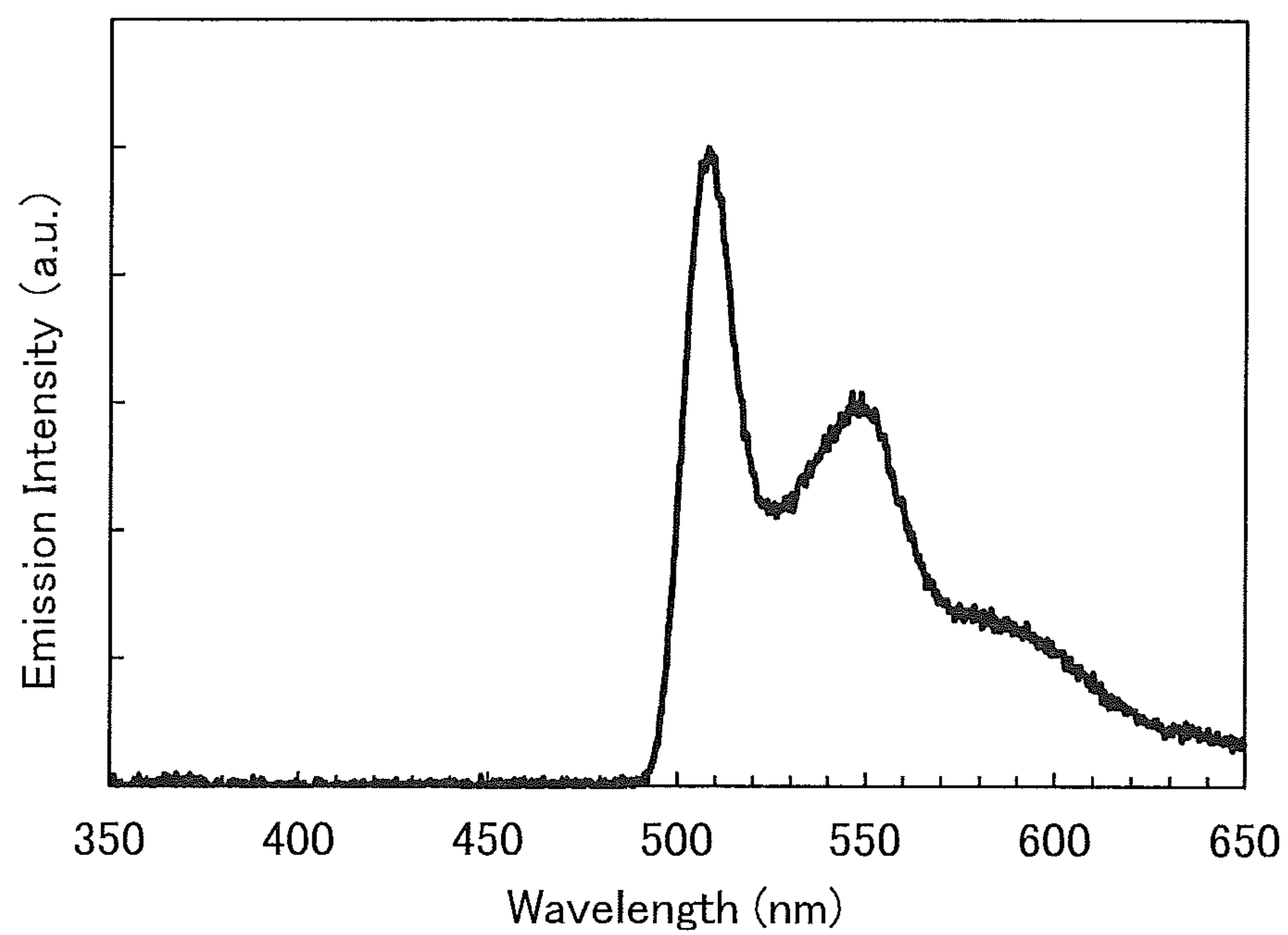


FIG. 77

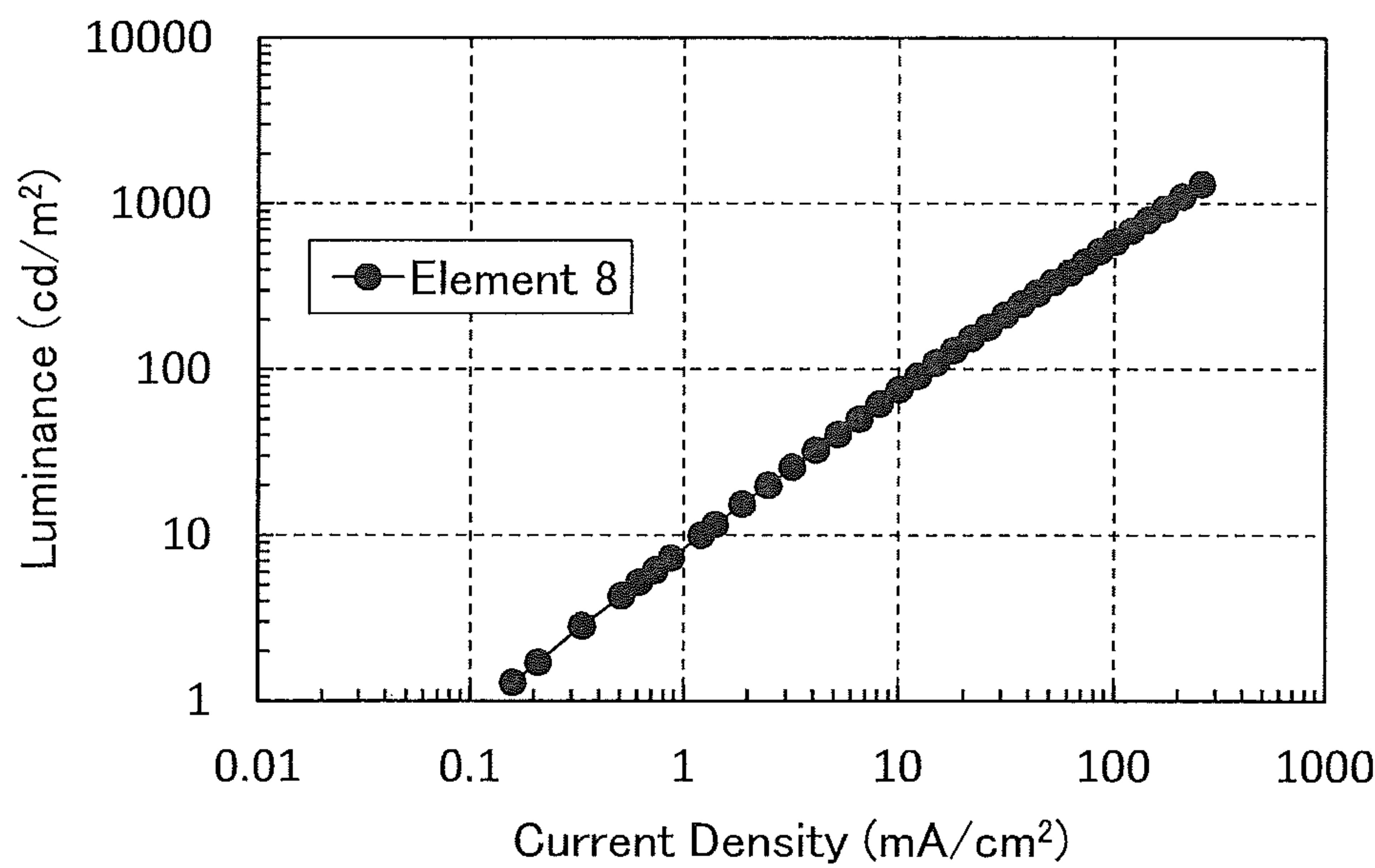


FIG. 78

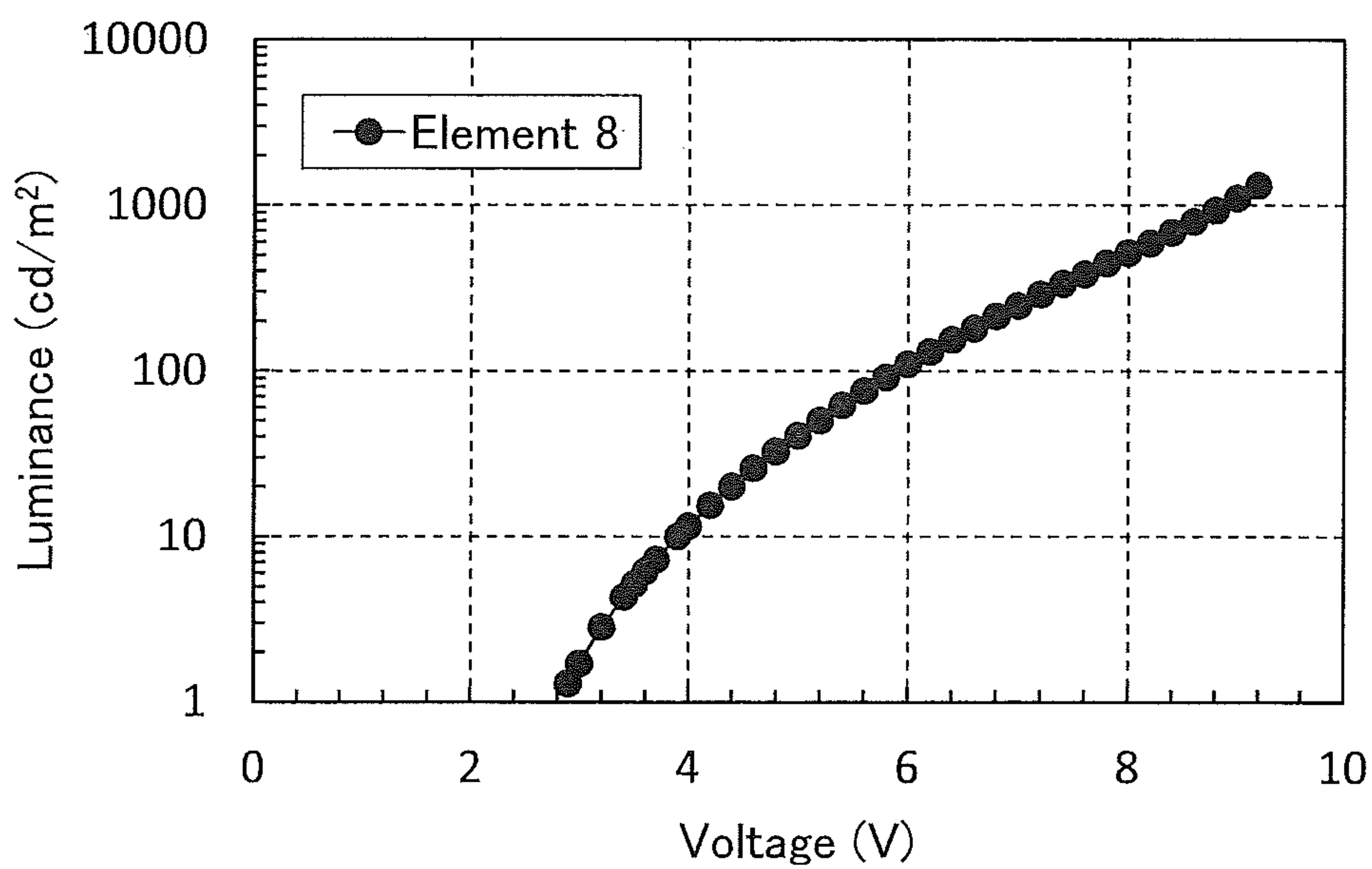


FIG. 79

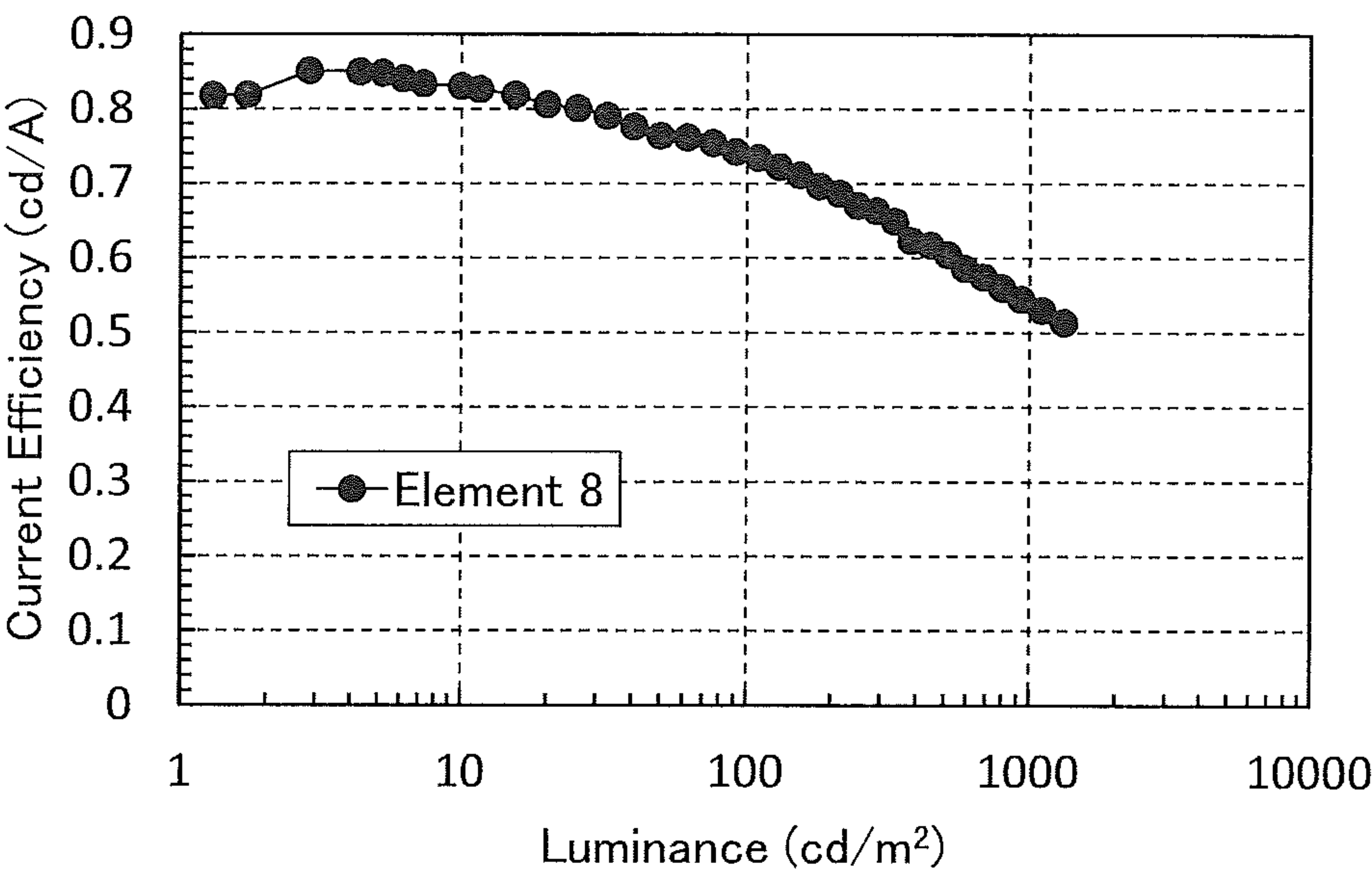


FIG. 80

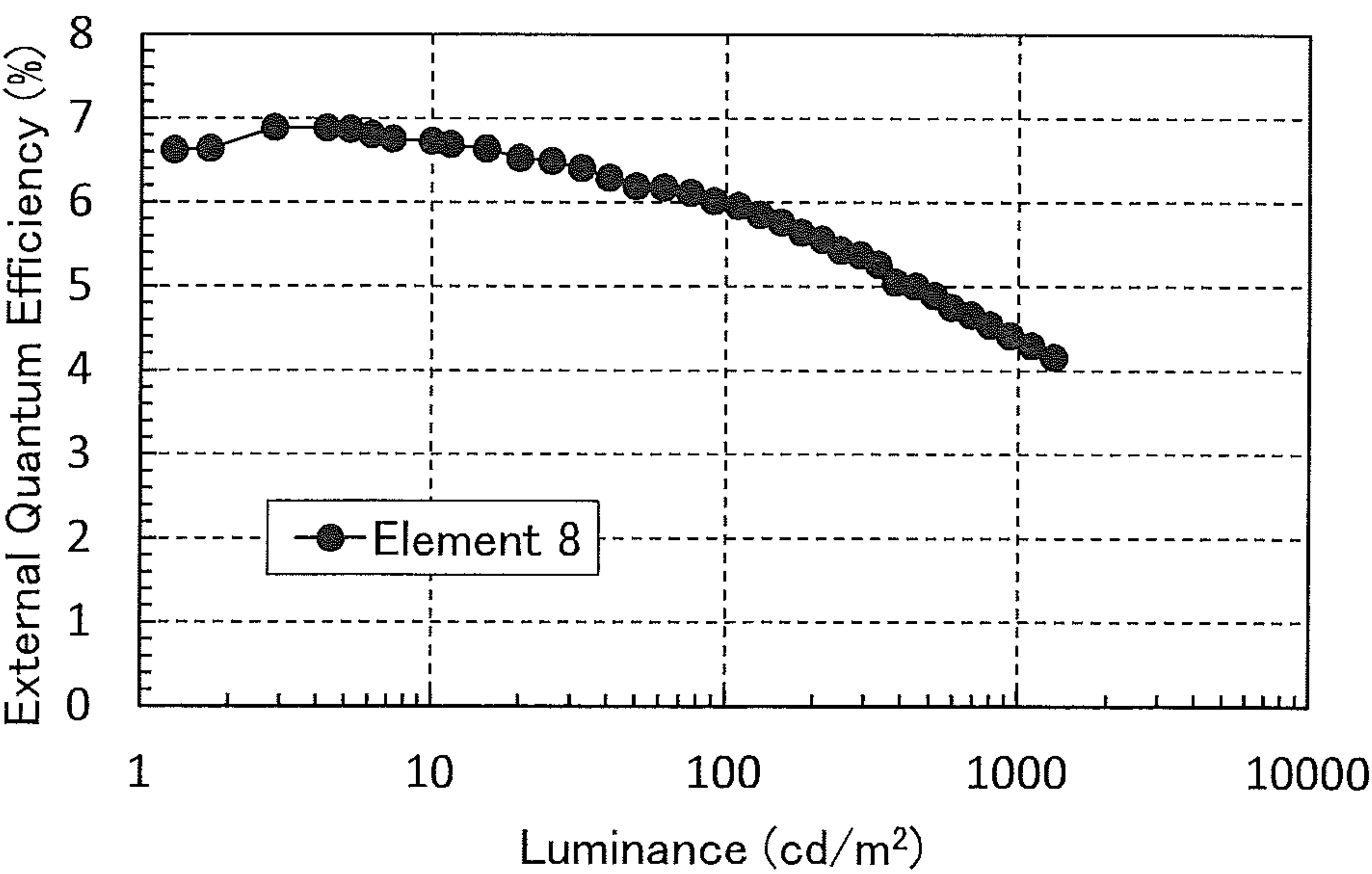


FIG. 81

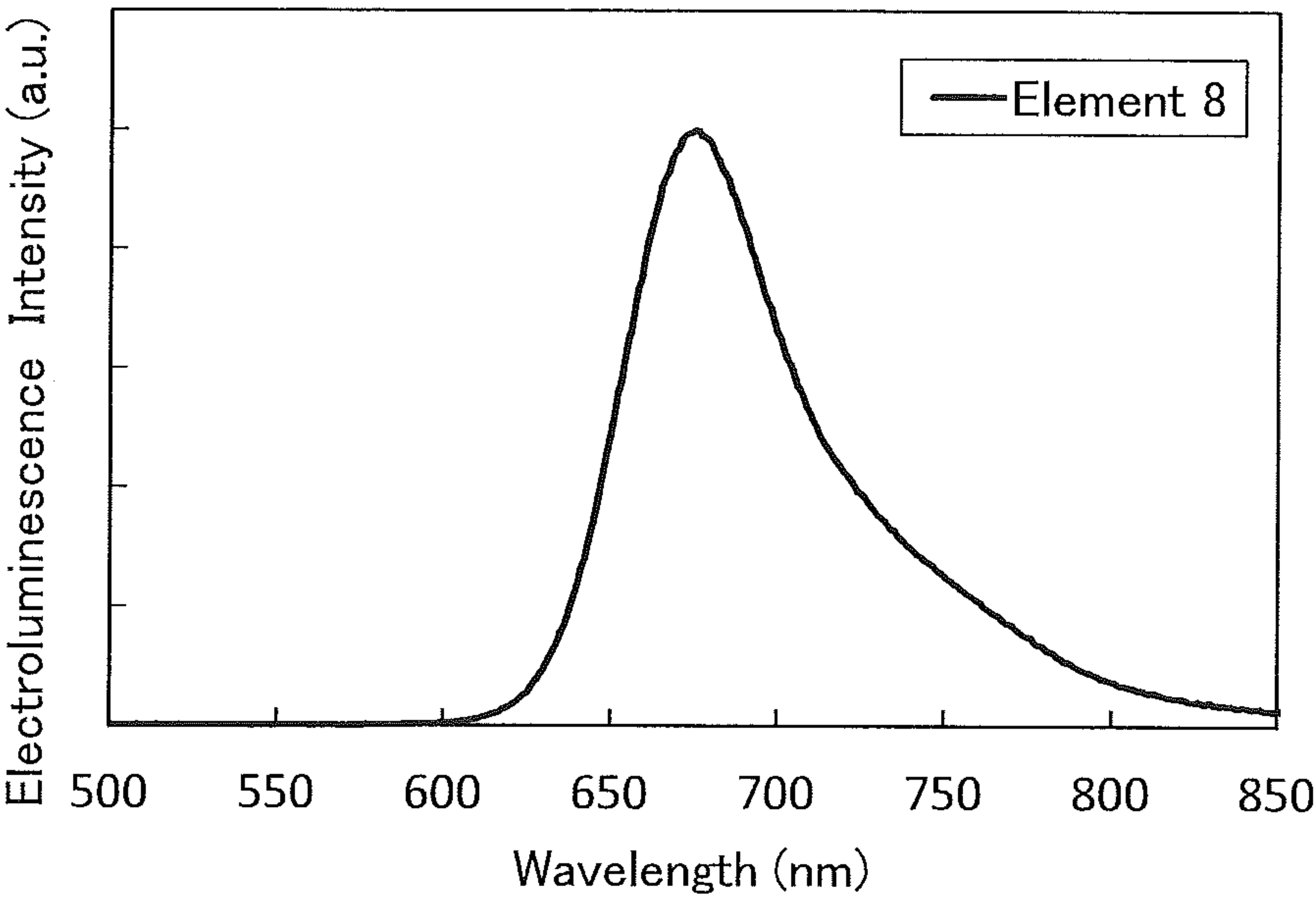


FIG. 82

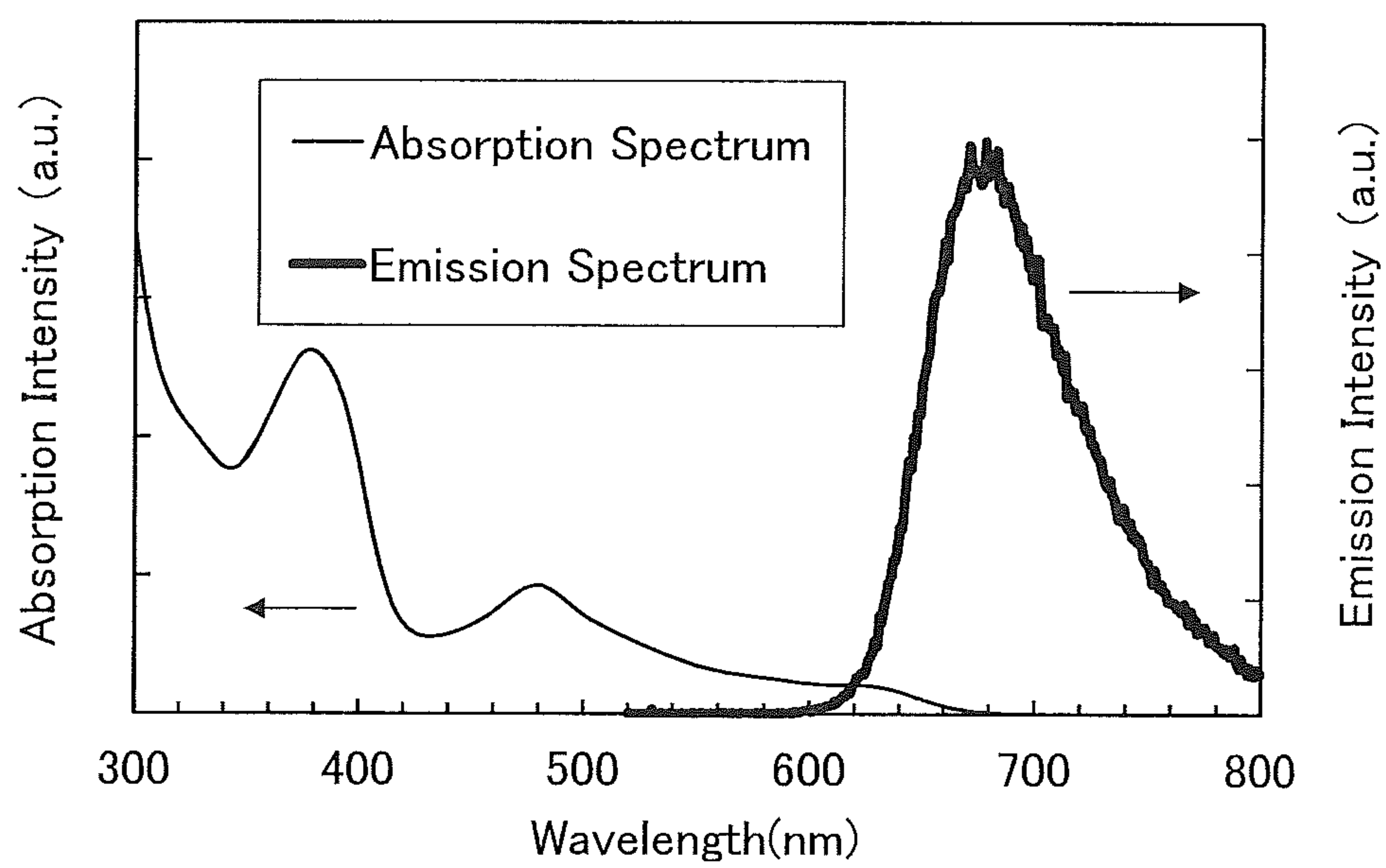
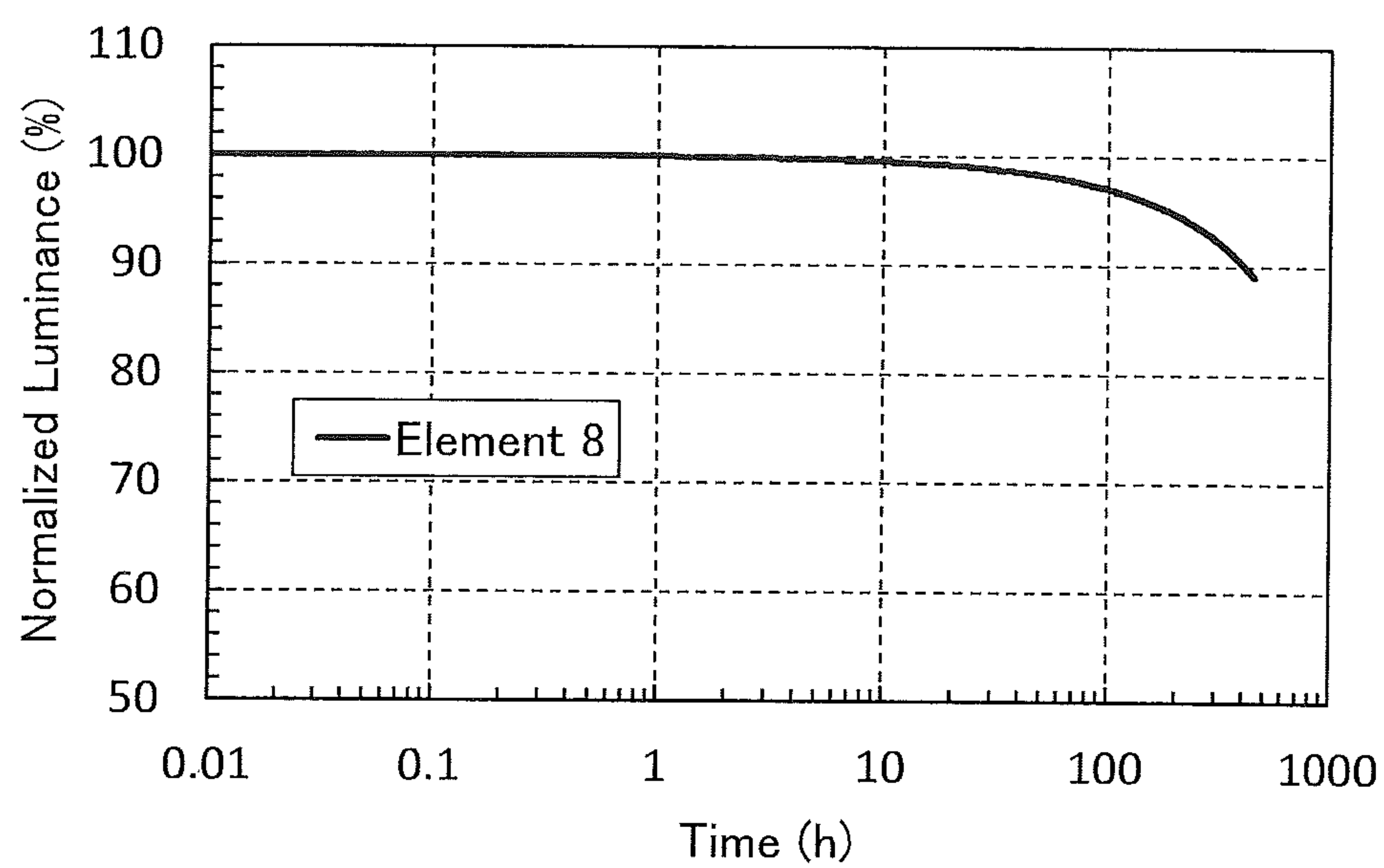


FIG. 83



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**LIGHT-EMITTING ELEMENT, DISPLAY
DEVICE, ELECTRONIC DEVICE, AND
LIGHTING DEVICE**

TECHNICAL FIELD

One embodiment of the present invention relates to a light-emitting element, a display device including the light-emitting element, an electronic device including the light-emitting element, or a lighting device including the light-emitting element.

Note that one embodiment of the present invention is not limited to the above technical field. The technical field of one embodiment of the invention disclosed in this specification and the like relates to an object, a method, or a manufacturing method. One embodiment of the present invention relates to a process, a machine, manufacture, or a composition of matter. Specifically, examples of the technical field of one embodiment of the present invention disclosed in this specification include a semiconductor device, a display device, a liquid crystal display device, a light-emitting device, a lighting device, a power storage device, a storage device, a method for driving any of them, and a method for manufacturing any of them.

BACKGROUND ART

In recent years, research and development have been extensively conducted on light-emitting elements using electroluminescence (EL). Such a light-emitting element has a basic structure in which a layer containing a light-emitting material (an EL layer) is interposed between a pair of electrodes. By application of a voltage between the electrodes of this element, light emission from the light-emitting material can be obtained.

This light-emitting element is a self-luminous type, and a display device using the light-emitting element has advantages such as high visibility, no necessity of a backlight, and low power consumption. In addition, the display device can be formed to be thin and lightweight and can response at high speed.

In the case of a light-emitting element (e.g., an organic EL element) whose EL layer includes an organic material as a light-emitting material and is provided between a pair of electrodes, application of a voltage between the pair of electrodes causes injection of electrons from a cathode and holes from an anode into the EL layer having a light-emitting property and thus a current flows. By recombination of the injected electrons and holes, the light-emitting organic material is brought into an excited state to provide light emission.

The excited state formed by an organic material can be a singlet excited state (S^*) or a triplet excited state (T^*). Light emission from the singlet-excited state is referred to as fluorescence, and light emission from the triplet excited state is referred to as phosphorescence. The statistical generation ratio of the excited states in the light-emitting element is considered to be $S^*:T^*=1:3$. In other words, a light-emitting element formed using a phosphorescent material has higher emission efficiency than a light-emitting element formed using a fluorescent material. Therefore, light-emitting elements formed using a phosphorescent material capable of converting a triplet excited state into light emission has been actively developed in recent years (e.g., see Patent Document 1).

Energy for exciting an organic material depends on an energy difference between the LUMO level and the HOMO

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level of the organic material. The energy difference approximately corresponds to singlet excitation energy. In a light-emitting element containing a phosphorescent organic material, triplet excitation energy is converted into light emission energy. Thus, when the energy difference between the singlet excited state and the triplet excited state of an organic material is large, the energy needed for exciting the organic material is higher than the light emission energy by the amount corresponding to the energy difference. The difference between the energy for exciting the organic material and the light emission energy affects element characteristics of a light-emitting element: the driving voltage of the light-emitting element increases. Research and development are being conducted on techniques for reducing the increase in driving voltage (see Patent Document 2).

Among light-emitting elements formed using a phosphorescent material, a light-emitting element that emits blue light in particular has not yet been put into practical use because it is difficult to develop a stable compound having a high triplet excitation energy level. Accordingly, development of a stable phosphorescent material with high emission efficiency and a highly reliable phosphorescent light-emitting element with high emission efficiency is required.

REFERENCE

Patent Document

- [Patent Document 1] Japanese Published Patent Application No. 2010-182699
- [Patent Document 2] Japanese Published Patent Application No. 2012-212879

DISCLOSURE OF INVENTION

An iridium complex is known as a phosphorescent material with high emission efficiency. An iridium complex including a pyridine skeleton or a nitrogen-containing five-membered heterocyclic skeleton as a ligand is known as an iridium complex with high light emission energy. Although the pyridine skeleton and the nitrogen-containing five-membered heterocyclic skeleton have high triplet excitation energy, they have poor electron-accepting property. Accordingly, the HOMO level and LUMO level of the iridium complex having the skeleton as a ligand are high, and hole carriers are easily injected thereto, while electron carriers are not. Thus, an iridium complex having a skeleton with high electron-accepting property as a ligand has been developed.

In contrast, the HOMO level and LUMO level of the iridium complex having a skeleton with high electron-accepting property as a ligand are low, and electron carriers tend to be injected thereto, while hole carriers do not. Thus, excitation by direct carrier recombination is sometimes difficult, which can hinder efficient light emission of a light-emitting element.

In view of the above, an object of one embodiment of the present invention is to provide a light-emitting element that has high emission efficiency and contains a phosphorescent material. Another object of one embodiment of the present invention is to provide a light-emitting element with low power consumption. Another object of one embodiment of the present invention is to provide a light-emitting element with high reliability. Another object of one embodiment of the present invention is to provide a novel light-emitting element. Another object of one embodiment of the present invention is to provide a novel light-emitting device.

Another object of one embodiment of the present invention is to provide a novel display device.

Note that the description of the above object does not disturb the existence of other objects. In one embodiment of the present invention, there is no need to achieve all the objects. Other objects are apparent from and can be derived from the description of the specification and the like.

One embodiment of the present invention is a light-emitting element in which an exciplex capable of efficiently exciting a phosphorescent material is formed.

Therefore, one embodiment of the present invention is a light-emitting element including a first organic compound, a second organic compound, and a guest material. The LUMO level of the first organic compound is lower than that of the second organic compound. The HOMO level of the first organic compound is lower than that of the second organic compound. The LUMO level of the guest material is lower than that of the first organic compound. An energy difference between the LUMO level and the HOMO level of the guest material is larger than an energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound. The guest material has a function of converting triplet excitation energy into light emission. The first organic compound and the second organic compound form an exciplex in combination.

Another embodiment of the present invention is a light-emitting element including a first organic compound, a second organic compound, and a guest material. The LUMO level of the first organic compound is lower than that of the second organic compound. The HOMO level of the first organic compound is lower than that of the second organic compound. The LUMO level of the guest material is lower than that of the first organic compound. An energy difference between the LUMO level and the HOMO level of the guest material is larger than an energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound. The guest material has a function of converting triplet excitation energy into light emission. The first organic compound and the second organic compound form an exciplex in combination. An energy difference between the LUMO level of the guest material and the HOMO level of the second organic compound is larger than or equal to transition energy calculated from an absorption edge of an absorption spectrum of the guest material.

Another embodiment of the present invention is a light-emitting element including a first organic compound, a second organic compound, and a guest material. The LUMO level of the first organic compound is lower than that of the second organic compound. The HOMO level of the first organic compound is lower than that of the second organic compound. The LUMO level of the guest material is lower than that of the first organic compound. An energy difference between the LUMO level and the HOMO level of the guest material is larger than an energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound. The guest material has a function of converting triplet excitation energy into light emission. The first organic compound and the second organic compound form an exciplex in combination. An energy difference between the LUMO level of the guest material and the HOMO level of the second organic compound is larger than or equal to an emission energy of the guest material.

In each of the above structures, it is preferable that an energy difference between the LUMO level of the guest material and the HOMO level of the guest material be larger

than the transition energy calculated from the absorption spectrum edge of the absorption spectrum of the guest material by 0.4 eV or more.

In each of the above structures, it is preferable that the energy difference between the LUMO level of the guest material and the HOMO level of the guest material be larger than the light emission energy of the guest material by 0.4 eV or more.

In each of the above structures, it is preferable that the exciplex be configured to transfer excitation energy to the guest material. In addition, an emission spectrum of the exciplex preferably has a region overlapping with an absorption band on the longest wavelength side in an absorption spectrum of the guest material.

In each of the above structures, the guest material preferably contains iridium.

In each of the above structures, the first organic compound preferably has a function of transporting an electron, and the second organic compound preferably has a function of transporting a hole. The first organic compound preferably includes a π -electron deficient heteroaromatic ring skeleton, and the second organic compound preferably includes at least one of a π -electron rich heteroaromatic ring skeleton and an aromatic amine skeleton.

Another embodiment of the present invention is a display device including the light-emitting element having any of the above-described structures and a color filter, a sealant, or a transistor. Another embodiment of the present invention is an electronic device including the above-described display device and a housing or a touch sensor. Another embodiment of the present invention is a lighting device including the light-emitting element having any of the above-described structures and a housing or a touch sensor. The category of one embodiment of the present invention includes not only a light-emitting device including a light-emitting element but also an electronic device including a light-emitting device. The light-emitting device in this specification refers to an image display device and a light source (e.g., a lighting device). The light-emitting device is sometimes included in a module in which a connector such as a flexible printed circuit (FPC) or a tape carrier package (TCP) is connected to a light-emitting device, a module in which a printed wiring board is provided on the tip of a TCP, or a module in which an integrated circuit (IC) is directly mounted on a light-emitting element by a chip on glass (COG) method.

With one embodiment of the present invention, a light-emitting element that contains a phosphorescent material and has high emission efficiency is provided. With one embodiment of the present invention, a light-emitting element with low power consumption is provided. With one embodiment of the present invention, a light-emitting element with high reliability is provided. With one embodiment of the present invention, a novel light-emitting element is provided. With one embodiment of the present invention, a novel light-emitting device is provided. With one embodiment of the present invention, a novel display device is provided.

Note that the description of these effects does not disturb the existence of other effects. One embodiment of the present invention does not necessarily have all the effects described above. Other effects will be apparent from and can be derived from the description of the specification, the drawings, the claims, and the like.

BRIEF DESCRIPTION OF DRAWINGS

FIGS. 1A and 1B are schematic cross-sectional views of a light-emitting element of one embodiment of the present invention.

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FIGS. 2A and 2B show a correlation of energy bands and a correlation of energy levels in a light-emitting layer of a light-emitting element of one embodiment of the present invention.

FIGS. 3A and 3B are each a schematic cross-sectional view of a light-emitting element of one embodiment of the present invention and FIG. 3C shows a correlation view of energy bands.

FIGS. 4A and 4B are each a schematic cross-sectional view of a light-emitting element of one embodiment of the present invention and FIG. 4C shows a correlation view of energy bands.

FIGS. 5A and 5B are each a schematic cross-sectional view of a light-emitting element of one embodiment of the present invention.

FIGS. 6A and 6B are each a schematic cross-sectional view of a light-emitting element of one embodiment of the present invention.

FIGS. 7A to 7C are schematic cross-sectional views illustrating a method for fabricating a light-emitting element of one embodiment of the present invention.

FIGS. 8A to 8C are schematic cross-sectional views illustrating a method for fabricating a light-emitting element of one embodiment of the present invention.

FIGS. 9A and 9B are a top view and a schematic cross-sectional view illustrating a display device of one embodiment of the present invention.

FIGS. 10A and 10B are schematic cross-sectional views each illustrating a display device of one embodiment of the present invention.

FIG. 11 is a schematic cross-sectional view illustrating a display device of one embodiment of the present invention.

FIGS. 12A and 12B are schematic cross-sectional views each illustrating a display device of one embodiment of the present invention.

FIGS. 13A and 13B are schematic cross-sectional views each illustrating a display device of one embodiment of the present invention.

FIG. 14 is a schematic cross-sectional view illustrating a display device of one embodiment of the present invention.

FIGS. 15A and 15B are schematic cross-sectional views each illustrating a display device of one embodiment of the present invention.

FIG. 16 is a schematic cross-sectional view illustrating a display device of one embodiment of the present invention.

FIGS. 17A and 17B are schematic cross-sectional views each illustrating a display device of one embodiment of the present invention.

FIGS. 18A and 18B are a block diagram and a circuit diagram illustrating a display device of one embodiment of the present invention.

FIGS. 19A and 19B are circuit diagrams each illustrating a pixel circuit of a display device of one embodiment of the present invention.

FIGS. 20A and 20B are circuit diagrams each illustrating a pixel circuit of a display device of one embodiment of the present invention.

FIGS. 21A and 21B are perspective views illustrating an example of a touch panel of one embodiment of the present invention.

FIGS. 22A to 22C are cross-sectional views illustrating an example of a display device and a touch sensor of one embodiment of the present invention.

FIGS. 23A and 23B are cross-sectional views each illustrating an example of a touch panel of one embodiment of the present invention.

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FIGS. 24A and 24B are a block diagram and a timing chart of a touch sensor of one embodiment of the present invention.

FIG. 25 is a circuit diagram of a touch sensor of one embodiment of the present invention.

FIG. 26 is a perspective view illustrating a display module of one embodiment of the present invention.

FIGS. 27A to 27G illustrate electronic devices of embodiments of the present invention.

FIGS. 28A to 28D illustrate electronic devices of embodiments of the present invention.

FIGS. 29A and 29B are perspective views illustrating a display device of one embodiment of the present invention.

FIGS. 30A to 30C are a perspective view and cross-sectional views illustrating a light-emitting device of one embodiment of the present invention.

FIGS. 31A to 31D are cross-sectional views each illustrating a light-emitting device of one embodiment of the present invention.

FIGS. 32A and 32B illustrate an electronic device of one embodiment of the present invention and FIG. 32C illustrates a lighting device of one embodiment of the present invention.

FIG. 33 illustrates lighting devices of embodiments of the present invention.

FIG. 34 is a schematic cross-sectional view illustrating a light-emitting element in Example.

FIG. 35 is a graph showing emission spectra of host materials in Example.

FIG. 36 is a graph showing absorption and emission spectra of a guest material in Example.

FIG. 37 is a graph showing phosphorescence spectra of host materials in Example.

FIG. 38 is a graph showing luminance-current density characteristics of light-emitting elements in Example.

FIG. 39 is a graph showing luminance-voltage characteristics of light-emitting elements in Example.

FIG. 40 is a graph showing current efficiency-luminance characteristics of light-emitting elements in Example.

FIG. 41 is a graph showing external quantum efficiency-luminance characteristics of light-emitting elements in Example.

FIG. 42 is a graph showing electroluminescence spectra of light-emitting elements in Example.

FIG. 43 is a graph showing reliability test results of light-emitting elements in Example.

FIG. 44 shows a correlation of energy bands in Example.

FIG. 45 shows angle distribution of light from light-emitting elements in Example.

FIG. 46 is a graph showing luminance-current density characteristics of light-emitting elements in Example.

FIG. 47 is a graph showing luminance-voltage characteristics of light-emitting elements in Example.

FIG. 48 is a graph showing current efficiency-luminance characteristics of light-emitting elements in Example.

FIG. 49 is a graph showing external quantum efficiency-luminance characteristics of light-emitting elements in Example.

FIG. 50 is a graph showing electroluminescence spectra of light-emitting elements in Example.

FIG. 51 is a graph showing absorption and emission spectra of a guest material in Example.

FIG. 52 is a graph showing absorption and emission spectra of a guest material in Example.

FIG. 53 shows reliability test results of light-emitting elements in Example.

FIG. 54 is a graph showing luminance-current density characteristics of a light-emitting element in Example.

FIG. 55 is a graph showing luminance-voltage characteristics of a light-emitting element in Example.

FIG. 56 is a graph showing current efficiency-luminance characteristics of a light-emitting element in Example.

FIG. 57 is a graph showing external quantum efficiency-luminance characteristics of a light-emitting element in Example.

FIG. 58 is a graph showing an electroluminescence spectrum of a light-emitting element in Example.

FIG. 59 shows reliability test results of a light-emitting element in Example.

FIG. 60 is a graph showing luminance-current density characteristics of light-emitting elements in Example.

FIG. 61 is a graph showing luminance-voltage characteristics of light-emitting elements in Example.

FIG. 62 is a graph showing current efficiency-luminance characteristics of light-emitting elements in Example.

FIG. 63 is a graph showing external quantum efficiency-luminance characteristics of light-emitting elements in Example.

FIG. 64 is a graph showing an electroluminescence spectrum of light-emitting elements in Example.

FIGS. 65A and 65B are graphs showing emission spectra of host materials in Example.

FIG. 66 is a graph showing luminance-current density characteristics of light-emitting elements in Example.

FIG. 67 is a graph showing luminance-voltage characteristics of light-emitting elements in Example.

FIG. 68 is a graph showing current efficiency-luminance characteristics of light-emitting elements in Example.

FIG. 69 is a graph showing external quantum efficiency-luminance characteristics of light-emitting elements in Example.

FIG. 70 is a graph showing electroluminescence spectra of light-emitting elements in Example.

FIG. 71 is a graph showing absorption and emission spectra of a guest material in Example.

FIG. 72 is a graph showing absorption and emission spectra of a guest material in Example.

FIG. 73 is a graph showing a phosphorescence emission spectrum of a host material in Example.

FIG. 74 is a graph showing a phosphorescence emission spectrum of a host material in Example.

FIG. 75 is a graph showing a phosphorescence emission spectrum of a host material in Example.

FIG. 76 is a graph showing a phosphorescence emission spectrum of a host material in Example.

FIG. 77 is a graph showing luminance-current density characteristics of a light-emitting element in Example.

FIG. 78 is a graph showing luminance-voltage characteristics of a light-emitting element in Example.

FIG. 79 is a graph showing current efficiency-luminance characteristics of a light-emitting element in Example.

FIG. 80 is a graph external quantum efficiency-luminance characteristics of a light-emitting element in Example.

FIG. 81 is a graph showing an electroluminescence spectrum of a light-emitting element in Example.

FIG. 82 is a graph showing absorption and emission spectra of a guest material in Example.

FIG. 83 is a graph showing reliability test results of a light-emitting element in Example.

Embodiments of the present invention will be described below with reference to the drawings. However, the present invention is not limited to description to be given below, and it is to be easily understood that modes and details thereof

can be variously modified without departing from the purpose and the scope of the present invention. Accordingly, the present invention should not be interpreted as being limited to the content of the embodiments below.

Note that the position, the size, the range, or the like of each structure illustrated in drawings and the like is not accurately represented in some cases for simplification. Therefore, the disclosed invention is not necessarily limited to the position, the size, the range, or the like disclosed in the drawings and the like.

Note that the ordinal numbers such as “first”, “second”, and the like in this specification and the like are used for convenience and do not denote the order of steps or the stacking order of layers. Therefore, for example, description can be made even when “first” is replaced with “second” or “third”, as appropriate. In addition, the ordinal numbers in this specification and the like are not necessarily the same as those which specify one embodiment of the present invention.

In the description of modes of the present invention in this specification and the like with reference to the drawings, the same components in different diagrams are commonly denoted by the same reference numeral in some cases.

In this specification and the like, the terms “film” and “layer” can be interchanged with each other depending on the case or circumstances. For example, the term “conductive layer” can be changed into the term “conductive film” in some cases. Also, the term “insulating film” can be changed into the term “insulating layer” in some cases.

In this specification and the like, a singlet excited state (S^*) refers to a singlet state having excitation energy. The lowest level of the singlet excitation energy level ($S1$ level) refers to the excitation energy level of the lowest singlet excited state. A triplet excited state (T^*) refers to a triplet state having excitation energy. The lowest level of the triplet excitation energy level ($T1$ level) refers to the excitation energy level of the lowest triplet excited state. Note that in this specification and the like, a singlet excited state or a singlet excitation energy level means the lowest singlet excited state or the $S1$ level sometimes. A triplet excited state or a triplet excitation energy level means the lowest triplet excited state or the $T1$ level sometimes.

In this specification and the like, a fluorescent material refers to a material that emits light in the visible light region when the relaxation from the singlet excited state to the ground state occurs. A phosphorescent material refers to a material that emits light in the visible light region at room temperature when the relaxation from the triplet excited state to the ground state occurs. That is, a phosphorescent material refers to a material that can convert triplet excitation energy into visible light.

Phosphorescence emission energy or a triplet excitation energy can be obtained from a wavelength of a phosphorescence emission peak (including a shoulder) on the shortest wavelength side of phosphorescence emission. Note that the phosphorescence emission can be observed by time-resolved photoluminescence in a low-temperature (e.g., 10 K) environment. A thermally activated delayed fluorescence emission energy can be obtained from a wavelength of an emission peak (including a shoulder) on the shortest wavelength side of thermally activated delayed fluorescence.

Note that in this specification and the like, “room temperature” refers to a temperature higher than or equal to 0°C . and lower than or equal to 40°C .

In this specification and the like, a wavelength range of blue refers to a wavelength range of greater than or equal to 400 nm and less than 500 nm, and blue light has at least one

peak in that range in an emission spectrum. A wavelength range of green refers to a wavelength range of greater than or equal to 500 nm and less than 580 nm, and green light has at least one peak in that range in an emission spectrum. A wavelength range of red refers to a wavelength range of greater than or equal to 580 nm and less than or equal to 680 nm, and red light has at least one peak in that range in an emission spectrum.

EMBODIMENT 1

In this embodiment, a light-emitting element of one embodiment of the present invention will be described below with reference to FIGS. 1A and 1B and FIGS. 2A and 2B.

<Structure Example of Light-Emitting Element>

First, a structure of the light-emitting element of one embodiment of the present invention will be described with reference to FIGS. 1A and 1B.

FIG. 1A is a schematic cross-sectional view of a light-emitting element **152** of one embodiment of the present invention.

The light-emitting element **152** includes a pair of electrodes (an electrode **101** and an electrode **102**) and an EL layer **100** between the pair of electrodes. The EL layer **100** includes at least a light-emitting layer **140**.

The EL layer **100** illustrated in FIG. 1A includes functional layers such as a hole-injection layer **111**, a hole-transport layer **112**, an electron-transport layer **118**, and an electron-injection layer **119**, in addition to the light-emitting layer **140**.

In this embodiment, although description is given assuming that the electrode **101** and the electrode **102** of the pair of electrodes serve as an anode and a cathode, respectively, they are not limited thereto for the structure of the light-emitting element **152**. That is, the electrode **101** may be a cathode, the electrode **102** may be an anode, and the stacking order of the layers between the electrodes may be reversed. In other words, the hole-injection layer **111**, the hole-transport layer **112**, the light-emitting layer **140**, the electron-transport layer **118**, and the electron-injection layer **119** may be stacked in this order from the anode side.

The structure of the EL layer **100** is not limited to the structure illustrated in FIG. 1A, and a structure including at least one layer selected from the hole-injection layer **111**, the hole-transport layer **112**, the electron-transport layer **118**, and the electron-injection layer **119** may be employed. Alternatively, the EL layer **100** may include a functional layer which is capable of lowering a hole- or electron-injection barrier, improving a hole- or electron-transport property, inhibiting a hole- or electron-transport property, or suppressing a quenching phenomenon by an electrode, for example. Note that the functional layers may each be a single layer or stacked layers.

FIG. 1B is a schematic cross-sectional view illustrating an example of the light-emitting layer **140** in FIG. 1A. The light-emitting layer **140** in FIG. 1B includes a host material **141** and a guest material **142**. The host material **141** includes an organic compound **141_1** and an organic compound **141_2**.

The guest material **142** may be a light-emitting organic material, and the light-emitting organic material is preferably a substance capable of emitting fluorescence (hereinafter also referred to as a phosphorescent material). A structure in which a phosphorescent material is used as the

guest material **142** will be described below. The guest material **142** may be rephrased as the phosphorescent material.

<Light Emission Mechanism of Light-Emitting Element>

Next, the light emission mechanism of the light-emitting layer **140** is described below.

The organic compound **141_1** and the organic compound **141_2** included in the host material **141** in the light-emitting layer **140** form an exciplex.

Although it is acceptable as long as the combination of the organic compound **141_1** and the organic compound **141_2** can form an exciplex, it is preferable that one of them be a compound having a function of transporting holes (a hole-transport property) and the other be a compound having a function of transporting electrons (an electron-transport property). In that case, a donor-acceptor exciplex is formed easily; thus, efficient formation of an exciplex is possible.

The combination of the organic compound **141_1** and the organic compound **141_2** is preferably as follows: one has a lower HOMO (highest occupied molecular orbital) level and a lower LUMO (lowest unoccupied molecular orbital) level than the other.

For example, in the case where the organic compound **141_1** has an electron-transport property and the organic compound **141_2** has a hole-transport property, it is preferable that the HOMO level of the organic compound **141_1** be lower than that of the organic compound **141_2** and the LUMO level of the organic compound **141_1** be lower than that of the organic compound **141_2** as shown in the energy band diagram of FIG. 2A.

At this time, an exciplex formed by the organic compound **141_1** and the organic compound **141_2** has excitation energy that approximately corresponds to an energy difference (ΔE_{Ex}) between the LUMO level of the organic compound **141_1** and the HOMO level of the organic compound **141_2**. The energy difference is preferable because it facilitates injection of electron carriers and hole carriers from the pair of electrodes (the electrode **101** and the electrode **102**) to the organic compound **141_1** and the organic compound **141_2**.

A difference between the HOMO level of the organic compound **141_1** and that of the organic compound **141_2** is preferably greater than or equal to 0.1 eV, and more preferably greater than or equal to 0.2 eV. Similarly, a difference between the LUMO level of the organic compound **141_1** and that of the organic compound **141_2** is preferably greater than or equal to 0.1 eV, and more preferably greater than or equal to 0.2 eV.

Note that in FIG. 2A, Host (**141_1**) represents the organic compound **141_1**, Host (**141_2**) represents the organic compound **141_2**, Guest (**142**) represents the guest material **142**, ΔE_{Ex} represents an energy difference between the LUMO level of the organic compound **141_1** and the HOMO level of the organic compound **141_2**, ΔE_B represents an energy difference between the LUMO level of the guest material **142** and the HOMO level of the organic compound **141_2**, and ΔE_G represents an energy difference between the LUMO level and the HOMO level of the guest material **142**.

The shorter the emission wavelength of the guest material **142** is, the higher light emission energy is; thus, the larger the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is, the better. However, excitation energy in the light-emitting element **152** is preferably as small as possible in order to reduce the driving voltage; thus, the smaller the excitation energy of an exciplex formed by the organic compounds **141_1** and **141_2** is, the better. Therefore, the energy difference (ΔE_{Ex})

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between the LUMO level of the organic compound **141_1** and the HOMO level of the organic compound **141_2** is preferably small.

Note that the guest material **142** is a phosphorescent light-emitting material and thus has a function of converting triplet excitation energy into light emission. In addition, energy is more stable in a triplet excited state than in a singlet excited state. Thus, the guest material **142** can emit light with energy smaller than the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142**. The present inventors have found out that even in the case where the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is larger than the energy difference (ΔE_{Ex}) between the LUMO level of the organic compound **141_1** and the HOMO level of the organic compound **141_2**, excitation energy transfer from an exciplex formed by the organic compound **141_1** and the organic compound **141_2** to the guest material **142** is possible and light emission can be obtained from the guest material **142** as long as light emission energy (ΔE_{Em}) of the guest material **142** or transition energy (ΔE_{abs}) calculated from an absorption spectrum edge is smaller than or equal to ΔE_{Ex} . When ΔE_G of the guest material **142** is larger than the light emission energy (ΔE_{Em}) of the guest material **142** or the transition energy (ΔE_{abs}) calculated from the absorption spectrum edge, high electrical energy that corresponds to ΔE_G is necessary to directly cause electrical excitation of the guest material **142** and thus the driving voltage of the light-emitting element is increased. However, in one embodiment of the present invention, an exciplex is electrically excited with electrical energy that corresponds to ΔE_{Ex} (that is smaller than ΔE_G), and light emission from the guest material **142** can be obtained by energy transfer from the exciplex, so that light emission of the guest material **142** with high efficiency can be obtained with a low driving voltage. That is, one embodiment of the present invention is useful particularly when ΔE_G is significantly larger than the light emission energy (ΔE_{Em}) of the guest material **142** or the transition energy (ΔE_{abs}) calculated from the absorption spectrum (for example, in the case where the guest material is a blue light-emitting material).

Note that in the case where the guest material **142** includes a heavy metal, intersystem crossing between a singlet state and a triplet state is promoted by spin-orbit interaction (interaction between spin angular momentum and orbital angular momentum of an electron), and transition between a singlet ground state and a triplet excited state of the guest material **142** is not forbidden in some cases. Therefore, the emission efficiency and the absorption probability which relate to the transition between the singlet ground state and the triplet excited state of the guest material **142** can be increased. Accordingly, the guest material **142** preferably includes a metal element with large spin-orbit interaction, specifically a platinum group element (ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir), or platinum (Pt)). In particular, iridium is preferred because the absorption probability that relates to direct transition between a singlet ground state and a triplet excited state can be increased.

Note that the LUMO level of the guest material **142** is preferably low so that the guest material **142** can have stable and high reliability; thus, a ligand coordinated to a heavy metal atom in the guest material **142** preferably has a low LUMO level and a high electron-accepting property.

Such a guest material tends to have a molecular structure having a low LUMO level and high electron-accepting

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property. When the guest material **142** has a molecular structure having high electron-accepting property, the LUMO level of the guest material **142** is sometimes lower than that of the organic compound **141_1**. In addition, when ΔE_G is larger than ΔE_{Ex} , the HOMO level of the guest material **142** is lower than the HOMO level of the organic compound **141_2**. Note that the energy difference between the HOMO level of the guest material **142** and the HOMO level of the organic compound **141_2** is larger than the energy difference between the LUMO level of the guest material **142** and the LUMO level of the organic compound **141_1**.

Here, when the LUMO level of the guest material **142** is lower than that of the organic compound **141_1** and when the HOMO level of the guest material **142** is lower than that of the organic compound **141_2**, among carriers (holes and electrons) injected from the pair of electrodes (the electrodes **101** and **102**), electrons injected from the cathode and holes injected from the anode are easily injected respectively to the guest material **142** and the organic compound **141_2** in the light-emitting layer **140**. Thus, there is a possibility that the organic compound **141_2** and the guest material **142** form an exciplex when the guest material **142** has the lowest LUMO level and the organic compound **141_2** has the highest HOMO level among the materials of the light-emitting layer **140**. Particularly when an energy difference (ΔE_{Ex}) between the HOMO level of the organic compound **141_2** and the LUMO level of the guest material **142** becomes smaller than the emission energy of the guest material (ΔE_{Em}), generation of exciplexes formed by the organic compound **141_2** and the guest material **142** becomes predominant. In that case, it is difficult to form an excited state by the guest material **142** alone, which decreases emission efficiency of the light-emitting element.

The reactions can be expressed by Formula (G1) or (G2).



Formula (G1) represents a reaction in which the organic compound **141_2** and the guest material **142** accept a hole (D^+) and the guest material **142** accepts an electron (G^-), a hole (D^+) and an electron (G^-), respectively, whereby the organic compound **141_2** and the guest material **142** form an exciplex $((D \cdot G)^*)$. Formula (G2) represents a reaction in which the guest material **142** (G^*) in the excited state interacts with the organic compound **141_2** (D) in the ground state, whereby the organic compound **141_2** and the guest material **142** form an exciplex $((D \cdot G)^*)$. Formation of the exciplex $((D \cdot G)^*)$ by the organic compound **141_2** and the guest material **142** makes it difficult to form an excited state (C) of the guest material **142** alone.

The exciplex formed by the organic compound **141_2** and the guest material **142** has excitation energy that approximately corresponds to an energy difference (ΔE_B) between the HOMO level of the organic compound **141_2** and the LUMO level of the guest material **142**. The present inventors have found that when the energy difference (ΔE_B) between the HOMO level of the organic compound **141_2** and the LUMO level of the guest material **142** is larger than or equal to an emission energy (ΔE_{Em}) of the guest material **142** or a transition energy (ΔE_{abs}) calculated from the absorption spectrum edge of the guest material **142**, the reaction for forming an exciplex by the organic compound **141_2** and the guest material **142** can be inhibited and thus emission efficiency of the guest material **142** can be high. Because ΔE_{abs} is smaller than ΔE_B , the guest material **142**

easily receives an excitation energy. The guest material **142** can have a smaller energy and go into a stable excitation state by receiving the excitation energy and going into an excitation state than by forming exciplex with the organic compound **141_2**.

As described above, even when the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is larger than the energy difference (ΔE_{Ex}) between the LUMO level of the organic compound **141_1** and the HOMO level of the organic compound **141_2**, excitation energy transfers efficiently from an exciplex formed by the organic compound **141_1** and the organic compound **141_2** to the guest material **142** as long as transition energy (abbreviation: ΔE_{G_abs}) calculated from an absorption edge of the guest material **142** is smaller than or equal to ΔE_{Ex} . As a result, a light-emitting element with high emission efficiency and low driving voltage can be obtained, which is a feature of one embodiment of the present invention. At this time, the formula $\Delta E_{G_abs} \leq \Delta E_{Ex} < \Delta E_G$ (ΔE_{G_abs} is smaller than or equal to ΔE_{Ex} and ΔE_{Ex} is smaller than ΔE_G) is satisfied. Therefore, the mechanism of one embodiment of the present invention is suitable in the case where ΔE_{abs} is smaller than ΔE_G . In other words, the mechanism of one embodiment of the present invention is suitable in the case where ΔE_G is larger than ΔE_{abs} . Specifically, the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is preferably larger than the transition energy (ΔE_{G_abs}) calculated from the absorption spectrum edge of the guest material **142** by 0.4 eV or more. Since the light emission energy of the guest material **142** is smaller than or equal to ΔE_{G_abs} , the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is preferably larger than the light emission energy (ΔE_{Em}) of the guest material **142** by 0.4 eV or more. Note that the light emission energy (ΔE_{Em}) can be derived from a peak wavelength (the maximum value, or including a shoulder peak) on the shortest wavelength side of the emission spectrum.

It is preferable that $\Delta E_{abs} \leq \Delta E_B$ (ΔE_{abs} is smaller than or equal to ΔE_B) or $\Delta E_{Em} \leq \Delta E_B$ (ΔE_{Em} is smaller than or equal to ΔE_B), which is described above, when the LUMO level of the guest material **142** is lower than that of the organic compound **141_1**. Therefore, $\Delta E_{abs} \leq \Delta E_B < \Delta E_{Ex} < \Delta E_G$ (ΔE_{abs} is smaller than or equal to ΔE_B , ΔE_B is smaller than ΔE_{Ex} , and ΔE_{Ex} is smaller than ΔE_G) or $\Delta E_{Em} \leq \Delta E_B < \Delta E_{Ex} < \Delta E_G$ (ΔE_{Em} is smaller than or equal to ΔE_B , ΔE_B is smaller than ΔE_{Ex} , and ΔE_{Ex} is smaller than ΔE_G) is preferable conditions, which are important discoveries in one embodiment of the present invention.

Note that the shorter the emission wavelength of the guest material **142** is and the higher light emission energy (ΔE_{Em}) is, the larger the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is, and accordingly, larger energy is needed for electrically exciting the guest material. However, in one embodiment of the present invention, when the transition energy (ΔE_{abs}) calculated from the absorption spectrum edge of the guest material **142** is smaller than or equal to ΔE_{Ex} , the guest material **142** can be excited with energy as small as ΔE_{Ex} , which is greatly smaller than ΔE_G , whereby the power consumption of the light-emitting element can be reduced. Therefore, the effect of the mechanism of one embodiment of the present invention is clear in the case where an energy difference between the transition energy (ΔE_{G_abs}) calculated from the absorption spectrum edge of the guest material **142** and the energy difference (ΔE_G) between the LUMO

level and the HOMO level of the guest material **142** is large (i.e., particularly in the case where the guest material is a blue light-emitting material).

As the transition energy (ΔE_{G_abs}) calculated from the absorption spectrum edge of the guest material **142** decreases, the light emission energy of the guest material **142** also decreases. In that case, light emission that needs high energy, such as blue light emission, is difficult to obtain. That is, when a difference between ΔE_{abs} and ΔE_G is too large, high-energy light emission such as blue light emission is obtained with difficulty.

For these reasons, the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is preferably larger than the transition energy (ΔE_{G_abs}) calculated from the absorption spectrum edge of the guest material **142** by 0.4 eV to 0.8 eV, more preferably by 0.5 eV to 0.8 eV. Since the light emission energy (ΔE_{Em}) of the guest material **142** is smaller than or equal to ΔE_{abs} , the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is preferably larger than the light emission energy (ΔE_{Em}) of the guest material **142** by 0.4 eV to 0.8 eV, more preferably by 0.5 eV to 0.8 eV.

A preferable difference between the LUMO level of the guest material **142** and the LUMO level of the organic compound **141_1** is larger than or equal to 0.05 eV and smaller than or equal to 0.4 eV. The reason is that the right amount of electron trap produces an effect of a longer lifetime of a light-emitting element, while too low a LUMO level of the guest material reduces ΔE_B described above. A difference in HOMO level between the guest material **142** and the organic compound **141_2** is preferably greater than or equal to 0.05 eV, more preferably greater than or equal to 0.1 eV, and still more preferably greater than or equal to 0.2 eV. This is because hole carriers are easily injected to the organic compound **141_2** with such an energy level correlation.

Since the energy difference (ΔE_{Ex}) between the LUMO level of the organic compound **141_1** and the HOMO level of the organic compound **141_2** is smaller than the energy difference between the LUMO level and the HOMO level of the organic compound **141_1** and smaller than the energy difference between the LUMO level and the HOMO level of the organic compound **141_2**, formation of an exciplex by the organic compound **141_1** and the organic compound **141_2** is more energetically stable than formation of an excited state only by either the organic compound **141_1** or the organic compound **141_2**. Furthermore, since the energy difference (ΔE_G) between the LUMO level and the HOMO level of the guest material **142** is larger than the energy difference (ΔE_{Ex}) between the LUMO level of the organic compound **141_1** and the HOMO level of the organic compound **141_2**, formation of an exciplex by the organic compound **141_1** and the organic compound **141_2** is more energetically stable as an excited state formed by recombination of carriers (holes and electrons) injected to the light-emitting layer **140**. Therefore, most of excited states generated in the light-emitting layer **140** exist as exciplexes formed by the organic compound **141_1** and the organic compound **141_2**. Accordingly, the structure of one embodiment of the present invention facilitates excitation energy transfer from the exciplex to the guest material **142**, leading to lower driving voltage of the light-emitting element and higher emission efficiency.

Note that the HOMO level of the guest material **142** may be higher than or lower than the HOMO level of the organic compound **141_1**.

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In addition, the guest material **142** serves as an electron trap in the light-emitting layer **140** because of its LUMO level lower than the LUMO level of the organic compound **141_1**. This is preferable because the carrier balance in the light-emitting layer can be easily controlled owing to the guest material **142** serving as an electron trap and an effect of a longer lifetime is obtained.

In the case where the combination of the organic compounds **141_1** and **141_2** is a combination of a compound having a hole-transport property and a compound having an electron-transport property, the carrier balance can be easily controlled depending on the mixture ratio. Specifically, the weight ratio of the compound having a hole-transport property to the compound having an electron-transport property is preferably within a range of 1:9 to 9:1. Since the carrier balance can be easily controlled with the structure, a carrier recombination region can also be controlled easily.

The exciplex formed by the organic compound **141_1** and the organic compound **141_2** has HOMO in one of the organic compounds and LUMO in the other of the organic compounds; thus, the overlap between the HOMO and the LUMO is extremely small. That is, in the excited complex, a difference between a singlet excitation energy level and a triplet excitation energy level is small. Thus, the difference between the triplet excitation energy level and the singlet excitation energy level of the exciplex formed by the organic compound **141_1** and the organic compound **141_2** is preferably larger than 0 eV and smaller than or equal to 0.2 eV, more preferably larger than 0 eV and smaller than or equal to 0.1 eV.

FIG. 2B illustrates the correlation of energy levels of the organic compound **141_1**, the organic compound **141_2**, and the guest material **142** in the light-emitting layer **140**. The following explains what terms and signs in FIG. 2B represent:

Host (**141_1**): host material (the organic compound **141_1**);

Host (**141_2**): host material (the organic compound **141_2**);

Guest (**142**): the guest material **142** (phosphorescent material);

Exciplex: the exciplex (the organic compounds **141_1** and **141_2**);

S_{PH1} : the S1 level of the host material (the organic compound **141_1**);

T_{PH1} : the T1 level of the host material (the organic compound **141_1**);

S_{PH2} : the S1 level of the host material (the organic compound **141_2**);

T_{PH2} : the T1 level of the host material (the organic compound **141_2**);

S_{PG} : the S1 level of the guest material **142** (the phosphorescent material);

T_{PG} : the T1 level of the guest material **142** (the phosphorescent material);

S_{PE} : the S1 level of the exciplex; and

T_{PE} : the T1 level of the exciplex.

In the light-emitting element of one embodiment of the present invention, the organic compounds **141_1** and **141_2** included in the light-emitting layer **140** form an exciplex. The lowest singlet excitation energy level of the exciplex (S_{PE}) and the lowest triplet excitation energy level of the exciplex (T_{PE}) are adjacent to each other (see Route E_7 in FIG. 2B).

An exciplex is an excited state formed from two kinds of substances. In photoexcitation, the exciplex is formed by interaction between one substance in an excited state and the

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other substance in a ground state. The two kinds of substances that have formed the exciplex return to a ground state by emitting light and serve as the original two kinds of substances. In electrical excitation, when one substance is brought into an excited state, the one immediately interacts with the other substance to form an exciplex. Alternatively, one substance receives a hole and the other substance receives an electron to readily form an exciplex. In this case, any of the substances can form an exciplex without forming an excited state by itself and; accordingly, most excitons in the light-emitting layer **140** can exist as exciplexes. Because the excitation energy levels of the exciplex (S_E or T_E) are lower than S1 level of the host materials (S_{PH1} and S_{PH2}) (the organic compound **141_1** and the organic compound **141_2**) that form the exciplex, the excited state of the host material **141** can be formed with lower excitation energy. Accordingly, the driving voltage of the light-emitting element **152** can be reduced.

Both energies of S_{PE} and T_{PE} of exciplexes are then transferred to the level (T_{PG}) of the lowest triplet excited state of the guest material **142** (the phosphorescent material); thus, light emission is obtained (see E_8 and E_9 in FIG. 2B).

Furthermore, the T1 level (T_{PE}) of the excited complex is preferably higher than the T1 level (T_{PG}) of the guest material **142**. In this way, the singlet excitation energy and the triplet excitation energy of the formed excited complex can be transferred from the S1 level (S_{PE}) and the T1 level (T_{PE}) of the excited complex to the T1 level (T_{PG}) of the guest material **142**.

When the light-emitting layer **140** has the above-described structure, light emission from the guest material **142** (the phosphorescent material) of the light-emitting layer **140** can be obtained efficiently.

The above-described processes through Routes E_7 , E_8 , and E_9 may be referred to as exciplex-triplet energy transfer (ExTET) in this specification and the like. In other words, in the light-emitting layer **140**, excitation energy is given from the exciplex to the guest material **142**. In that case, the reverse intersystem crossing efficiency from T_{PE} to S_{PE} is not necessarily high and the emission quantum yield from S_{PE} is also not necessarily high, whereby materials can be selected from a wide range of options.

Note that the reactions described above can be expressed by Formulae (G3) to (G5).



In Formula (G3), one of the organic compound **141_1** and the organic compound **141_2** accepts a hole (D^+) and the other accepts an electron (A^-), whereby the organic compound **141_1** and the organic compound **141_2** form an exciplex ($(D \cdot A)^*$). In Formula (G4), energy transfers from the exciplex ($(D \cdot A)^*$) to the guest material **142** (G), whereby an excited state of the guest material **142** (G^*) is generated. After that, as expressed by Formula (G5), the guest material **142** in the excited state emits light ($h\nu$).

Note that in order to efficiently transfer excitation energy from the guest material **142** to the exciplex, the T1 level of the exciplex (T_{PE}) is preferably lower than the T1 levels of the organic compounds (the organic compound **141_1** and the organic compound **141_2**) in the host material which form the exciplex. Thus, quenching of the triplet excitation

energy of the exciplex due to the organic compounds is less likely to occur, which causes efficient energy transfer to the guest material **142**.

When the organic compound **141_2** includes a skeleton having a strong donor property, a hole that has been injected to the light-emitting layer **140** is easily injected in the organic compound **141_2** and easily transported. When the organic compound **141_1** includes a skeleton having a strong acceptor property, an electron that has been injected to the light-emitting layer **140** is easily injected in the organic compound **141_1** and easily transported. Thus, the organic compound **141_1** and the organic compound **141_2** easily form an exciplex.

When the light-emitting layer **140** has the above-described structure, light emission from the guest material **142** of the light-emitting layer **140** can be obtained efficiently.

<Energy Transfer Mechanism>

Next, factors controlling the processes of intermolecular energy transfer between the host material **141** and the guest material **142** will be described. As mechanisms of the intermolecular energy transfer, two mechanisms, i.e., Förster mechanism (dipole-dipole interaction) and Dexter mechanism (electron exchange interaction), have been proposed. Although the intermolecular energy transfer process between the host material **141** and the guest material **142** is described here, the same can apply to a case where the host material **141** is an exciplex.

<<Förster Mechanism>>

In Förster mechanism, energy transfer does not require direct contact between molecules and energy is transferred through a resonant phenomenon of dipolar oscillation between the host material **141** and the guest material **142**. By the resonant phenomenon of dipolar oscillation, the host material **141** provides energy to the guest material **142**, and thus, the host material **141** in an excited state is brought to a ground state and the guest material **142** in a ground state is brought to an excited state. Note that the rate constant $k_{h^* \rightarrow g}$ of Förster mechanism is expressed by Formula (1).

[Formula 1]

$$k_{h^* \rightarrow g} = \frac{9000c^4 K^2 \phi \ln 10}{128\pi^5 n^4 N \tau R^6} \int \frac{f'_h(v) \varepsilon'_g(v)}{v^4} dv \quad (1)$$

In Formula (1), v denotes a frequency, $f'_h(v)$ denotes a normalized emission spectrum of the host material **141** (a fluorescent spectrum in energy transfer from a singlet excited state, and a phosphorescent spectrum in energy transfer from a triplet excited state), $\varepsilon'_g(v)$ denotes a molar absorption coefficient of the guest material **142**, N denotes Avogadro's number, n denotes a refractive index of a medium, R denotes an intermolecular distance between the host material **141** and the guest material **142**, τ denotes a measured lifetime of an excited state (fluorescence lifetime or phosphorescence lifetime), c denotes the speed of light, ϕ denotes a luminescence quantum yield (a fluorescence quantum yield in energy transfer from a singlet excited state, and a phosphorescence quantum yield in energy transfer from a triplet excited state), and K^2 denotes a coefficient (0 to 4) of orientation of a transition dipole moment between the host material **141** and the guest material **142**. Note that K^2 is $2/3$ in random orientation.

<<Dexter Mechanism>>

In Dexter mechanism, the host material **141** and the guest material **142** are close to a contact effective range where

their orbitals overlap, and the host material **141** in an excited state and the guest material **142** in a ground state exchange their electrons, which leads to energy transfer. Note that the rate constant $k_{h^* \rightarrow g}$ of Dexter mechanism is expressed by Formula (2).

[Formula 2]

$$k_{h^* \rightarrow g} = \left(\frac{2\pi}{h} \right) K^2 \exp\left(-\frac{2R}{L}\right) \int f'_h(v) \varepsilon'_g(v) dv \quad (2)$$

In Formula (2), h denotes a Planck constant, K denotes a constant having an energy dimension, v denotes a frequency, $f'_h(v)$ denotes a normalized emission spectrum of the host material **141** (a fluorescent spectrum in energy transfer from a singlet excited state, and a phosphorescent spectrum in energy transfer from a triplet excited state), $\varepsilon'_g(v)$ denotes a normalized absorption spectrum of the guest material **142**, L denotes an effective molecular radius, and R denotes an intermolecular distance between the host material **141** and the guest material **142**.

Here, the efficiency of energy transfer from the host material **141** to the guest material **142** (energy transfer efficiency ϕ_{ET}) is expressed by Formula (3). In the formula, k_r denotes a rate constant of a light-emission process (fluorescence in energy transfer from a singlet excited state, and phosphorescence in energy transfer from a triplet excited state) of the host material **141**, k_n denotes a rate constant of a non-light-emission process (thermal deactivation or intersystem crossing) of the host material **141**, and t denotes a measured lifetime of an excited state of the host material **141**.

[Formula 3]

$$\phi_{ET} = \frac{k_{h^* \rightarrow g}}{k_r + k_n + k_{h^* \rightarrow g}} = \frac{k_{h^* \rightarrow g}}{\left(\frac{1}{\tau}\right) + k_{h^* \rightarrow g}} \quad (3)$$

According to Formula (3), it is found that the energy transfer efficiency ϕ_{ET} can be increased by increasing the rate constant $k_{h^* \rightarrow g}$ of energy transfer so that another competing rate constant $k_r + k_n (=1/\tau)$ becomes relatively small.

<<Concept for Promoting Energy Transfer>>

In energy transfer by Förster mechanism, high energy transfer efficiency ϕ_{ET} is obtained when quantum yield ϕ (a fluorescence quantum yield in the case where energy transfer from a singlet excited state is discussed, and a phosphorescence quantum yield in the case where energy transfer from a triplet excited state is discussed) is high. Furthermore, it is preferable that the emission spectrum (the fluorescence spectrum in the case where energy transfer from the singlet excited state is discussed) of the host material **141** largely overlap with the absorption spectrum (absorption corresponding to the transition from the singlet ground state to the triplet excited state) of the guest material **142**. It is preferable that the molar absorption coefficient of the guest material **142** be also high. This means that the emission spectrum of the host material **141** overlaps with the absorption band of the guest material **142** which is on the longest wavelength side.

In energy transfer by Dexter mechanism, in order to make the rate constant $k_{h^* \rightarrow g}$ large, it is preferable that the emission spectrum (a fluorescence spectrum in the case where

energy transfer from a singlet excited state is discussed, and a phosphorescence spectrum in the case where energy transfer from a triplet excited state is discussed) of the host material **141** largely overlap with the absorption spectrum (absorption corresponding to transition from a singlet ground state to a triplet excited state) of the guest material **142**. Therefore, the energy transfer efficiency can be optimized by making the emission spectrum of the host material **141** overlap with the absorption band of the guest material **142** which is on the longest wavelength side.

In a manner similar to that of the energy transfer from the host material **141** to the guest material **142**, the energy transfer by both Förster mechanism and Dexter mechanism also occurs in the energy transfer process from the exciplex to the guest material **142**.

Accordingly, one embodiment of the present invention provides a light-emitting element including, as the host material **141**, the organic compound **141_1** and the organic compound **141_2** which are a combination for forming an exciplex that functions as an energy donor capable of efficiently transferring energy to the guest material **142**. The excitation energy for forming the exciplex by the organic compound **141_1** and the organic compound **141_2** can be lower than the excitation energy of the organic compound **141_1** in the excited state and lower than the excitation energy of the organic compound **141_2** in the excited state. Therefore, the driving voltage of the light-emitting element **150** can be reduced. Furthermore, in order to facilitate energy transfer from the singlet excitation energy level of the exciplex to the triplet excitation energy level of the guest material **142** having a function as an energy acceptor, it is preferable that the emission spectrum of the exciplex overlap with the absorption band of the guest material **142** which is on the longest wavelength side (low energy side). Thus, the efficiency of generating the triplet excited state of the guest material **142** can be increased. The exciplex generated in the light-emitting layer **140** has a feature in that the singlet excitation energy level is close to the triplet excitation energy level. Therefore, by overlapping the emission spectrum of the exciplex and the absorption band of the guest material **142** which is on the longest wavelength side (lowest energy side), energy transfer from the triplet excitation energy level of the exciplex to the triplet excitation energy level of the guest material **142** can be facilitated.

<Material>

Next, components of a light-emitting element of one embodiment of the present invention are described in detail below.

<<Light-Emitting Layer>>

In the light-emitting layer **140**, the host material **141** is present in the largest proportion by weight, and the guest material **142** (the phosphorescent material) is dispersed in the host material **141**. The T1 level of the host material **141** (the organic compound **141_1** and the organic compound **141_2**) in the light-emitting layer **140** is preferably higher than the T1 level of the guest material (the guest material **142**) in the light-emitting layer **140**.

As the organic compound **141_1**, a material having a property of transporting more electrons than holes can be used, and a material having an electron mobility of 1×10^{-6} cm²/Vs or higher is preferable. A compound including a π -electron deficient heteroaromatic ring skeleton such as a nitrogen-containing heteroaromatic compound, a metal complex, or a zinc- or aluminum-based metal complex can be used, for example, as the material which easily accepts electrons (the material having an electron-transport property). Specific examples are a metal complex having a

quinoline ligand, a benzoquinoline ligand, an oxazole ligand, or a thiazole ligand, which is described as the electron-transport material that can be used in the light-emitting layer **130**, an oxadiazole derivative, a triazole derivative, a benzimidazole derivative, a quinoxaline derivative, a dibenzoquinoxaline derivative, a phenanthroline derivative, a pyridine derivative, a bipyridine derivative, a pyrimidine derivative, and a triazine derivative, which are given as materials having electron-transport properties which can be used for the light-emitting layer **130**.

Specific examples include metal complexes having a quinoline or benzoquinoline skeleton, such as tris(8-quinolinolato)aluminum(III) (abbreviation: Alq), tris(4-methyl-8-quinolinolato)aluminum(III) (abbreviation: Almq₃), bis(10-hydroxybenzo[h]quinolinato)beryllium(II) (abbreviation: BeBq₂), bis(2-methyl-8-quinolinolato)(4-phenylphenolato)aluminum(III) (abbreviation: BAq) and bis(8-quinolinolato)zinc(II) (abbreviation: Znq), and the like. Alternatively, a metal complex having an oxazole-based or thiazole-based ligand, such as bis[2-(2-benzoxazolyl)phenolate]zinc(II) (abbreviation: ZnPBO) or bis[2-(2-benzothiazolyl)phenolato]zinc(H) (abbreviation: ZnBTZ) can be used. Other than such metal complexes, any of the following can be used: heterocyclic compounds such as 2-(4-biphenyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole (abbreviation: PBD), 1,3-bis[5-(p-tert-butylphenyl)-1,3,4-oxadiazol-2-yl]benzene (abbreviation: OXD-7), 9-[4-(5-phenyl-1,3,4-oxadiazol-2-yl)phenyl]-9H-carbazole (abbreviation: CO11), 3-(biphenyl-4-yl)-4-phenyl-5-(4-tert-butylphenyl)-1,2,4-triazole (abbreviation: TAZ), 9-[4-(4,5-diphenyl-4H-1,2,4-triazol-3-yl)phenyl]-9H-carbazole (abbreviation: CzTAZ1), 2,2',2''-(1,3,5-benzenetriyl)tris(1-phenyl-1H-benzimidazole) (abbreviation: TPBI), 2-[3-(dibenzothiophen-4-yl)phenyl]-1-phenyl-1H-benzimidazole (abbreviation: mDBTBIIm-II), bathophenanthroline (abbreviation: BPhen), and bathocuproine (abbreviation: BCP); heterocyclic compounds having a diazine skeleton such as 2-[3-(dibenzothiophen-4-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 2mDBTPDBq-II), 2-[3'-(dibenzothiophen-4-yl)biphenyl-3-yl]dibenzo[f,h]quinoxaline (abbreviation: 2mDBTBPDBq-II), 2-[3'-(9H-carbazol-9-yl)biphenyl-3-yl]dibenzo[f,h]quinoxaline (abbreviation: 2mCzBPDBq), 2-[4-(3,6-diphenyl-9H-carbazol-9-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 2CzPDBq-III), 7-[3-(dibenzothiophen-4-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 7mDBTPDBq-II), 6-[3-(dibenzothiophen-4-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 6mDBEPDBq-II), 2-[3-(3,9'-bi-9H-carbazol-9-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 2mCzCzPDBq), 4,6-bis[3-(phenanthren-9-yl)phenyl]pyrimidine (abbreviation: 4,6mPnP2Pm), 4,6-bis[3-(4-dibenzothienyl)phenyl]pyrimidine (abbreviation: 4,6mDBTP2Pm-II), and 4,6-bis[3-(9H-carbazol-9-yl)phenyl]pyrimidine (abbreviation: 4,6mCzP2Pm); heterocyclic compounds having a triazine skeleton such as 2-{4-[3-(N-phenyl-9H-carbazol-3-yl)-9H-carbazol-9-yl]phenyl}-4,6-diphenyl-1,3,5-triazine (abbreviation: PCCzPTzn); heterocyclic compounds having a pyridine skeleton such as 3,5-bis[3-(9H-carbazol-9-yl)phenyl]pyridine (abbreviation: 35DCzPPy); and heteroaromatic compounds such as 4,4'-bis(5-methylbenzoxazol-2-yl)stilbene (abbreviation: BzOs). Among the heterocyclic compounds, the heterocyclic compounds having a triazine skeleton, a diazine skeleton (pyrimidine, pyrazine, pyridazine), or a pyridine skeleton are highly reliable and stable and is thus preferably used. In addition, the heterocyclic compounds having the skeletons have a high electron-transport property to contribute to a reduction in driving voltage. Further alternatively, a high

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molecular compound such as poly(2,5-pyridinediyl) (abbreviation: PPy), poly[(9,9-dihexylfluorene-2,7-diyl)-co-(pyridine-3,5-diyl)] (abbreviation: PF-Py), or poly[(9,9-dioctylfluorene-2,7-diyl)-co-(2,2'-bipyridine-6,6'-diyl)] (abbreviation: PF-BPy) can be used. The substances described here are mainly substances having an electron mobility of 1×10^{-6} cm²/Vs or higher. Note that other substances may also be used as long as their electron-transport properties are higher than their hole-transport properties.

As the organic compound **141_2**, a substance which can form an exciplex together with the organic compound **141_1** is preferably used. Specifically, the organic compound **141_2** preferably includes a skeleton having a high donor property, such as a π -electron rich heteroaromatic ring skeleton or an aromatic amine skeleton. Examples of the compound having a π -electron rich heteroaromatic ring skeleton include heteroaromatic compounds such as a dibenzothiophene derivative, a dibenzofuran derivative, and a carbazole derivative. In that case, it is preferable that the organic compound **141_1**, the organic compound **141_2**, and the guest material **142** (the phosphorescent material) be selected such that the emission peak of the exciplex formed by the organic compound **141_1** and the organic compound **141_2** overlaps with an absorption, specifically an absorption band on the longest wavelength side, of a triplet metal to ligand charge transfer (MLCT) transition of the guest material **142** (the phosphorescent material). This makes it possible to provide a light-emitting element with drastically improved emission efficiency. Note that in the case where a thermally activated delayed fluorescence material is used instead of the phosphorescent material, it is preferable that the absorption band on the longest wavelength side be a singlet absorption band.

As the organic compound **141_2**, materials having a hole-transport property given below can be used.

A material having a property of transporting more holes than electrons can be used as the hole-transport material, and a material having a hole mobility of 1×10^{-6} cm²/Vs or higher is preferable. Specifically, an aromatic amine, a carbazole derivative, an aromatic hydrocarbon, a stilbene derivative, or the like can be used. Furthermore, the hole-transport material may be a high molecular compound.

Examples of the material having a high hole-transport property are N,N'-di(p-tolyl)-N,N'-diphenyl-p-phenylenediamine (abbreviation: DTDPPA), 4,4'-bis[N-(4-diphenylaminophenyl)-N-phenylamino]biphenyl (abbreviation: DPAB), N,N'-bis{4-[bis(3-methylphenyl)amino]phenyl}-N,N'-diphenyl-(1,1'-biphenyl)-4,4'-diamine (abbreviation: DNTPD), 1,3,5-tris[N-(4-diphenylaminophenyl)-N-phenylamino]benzene (abbreviation: DPA3B), and the like.

Specific examples of the carbazole derivative are 3-[N-(4-diphenylaminophenyl)-N-phenylamino]-9-phenylcarbazole (abbreviation: PCzDPA1), 3,6-bis[N-(4-diphenylaminophenyl)-N-phenylamino]-9-phenylcarbazole (abbreviation: PCzDPA2), 3,6-bis[N-(4-diphenylaminophenyl)-N-(1-naphthyl)amino]-9-phenylcarbazole (abbreviation: PCzTPN2), 3-[N-(9-phenylcarbazol-3-yl)-N-phenylamino]-9-phenylcarbazole (abbreviation: PCzPCA1), 3,6-bis[N-(9-phenylcarbazol-3-yl)-N-phenylamino]-9-phenylcarbazole (abbreviation: PCzPCA2), 3-[N-(1-naphthyl)-N-(9-phenylcarbazol-3-yl)amino]-9-phenylcarbazole (abbreviation: PCzPCN1), and the like.

Other examples of the carbazole derivative are 4,4'-di(N-carbazolyl)biphenyl (abbreviation: CBP), 1,3,5-tris[4-(N-carbazolyl)phenyl]benzene (abbreviation: TCPB), 9-[4-(10-

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phenyl-9-anthracenyl)phenyl]-9H-carbazole (abbreviation: CzPA), 1,4-bis[4-(N-carbazolyl)phenyl]-2,3,5,6-tetraphenylbenzene, and the like.

Examples of the aromatic hydrocarbon are 2-tert-butyl-9,10-di(2-naphthyl)anthracene (abbreviation: t-BuDNA), 2-tert-butyl-9,10-di(1-naphthyl)anthracene, 9,10-bis(3,5-diphenylphenyl)anthracene (abbreviation: DPPA), 2-tert-butyl-9,10-bis(4-phenylphenyl)anthracene (abbreviation: t-BuDBA), 9,10-di(2-naphthyl)anthracene (abbreviation: DNA), 9,10-diphenylanthracene (abbreviation: DPAnth), 2-tert-butylanthracene (abbreviation: t-BuAnth), 9,10-bis(4-methyl-1-naphthyl)anthracene (abbreviation: DMNA), 2-tert-butyl-9,10-bis[2-(1-naphthyl)phenyl]anthracene, 9,10-bis[2-(1-naphthyl)phenyl]anthracene, 2,3,6,7-tetramethyl-9,10-di(1-naphthyl)anthracene, 2,3,6,7-tetramethyl-9,10-di(2-naphthyl)anthracene, 9,9'-bianthryl, 10,10'-diphenyl-9,9'-bianthryl, 10,10'-bis(2-phenylphenyl)-9,9'-bianthryl, 10,10'-bis[(2,3,4,5,6-pentaphenyl)phenyl]-9,9'-bianthryl, anthracene, tetracene, rubrene, perylene, 2,5,8,11-tetra(tert-butyl)perylenene, and the like. Other examples are pentacene, coronene, and the like. The aromatic hydrocarbon having a hole mobility of 1×10^{-6} cm²/Vs or higher and having 14 to 42 carbon atoms is particularly preferable.

The aromatic hydrocarbon may have a vinyl skeleton. Examples of the aromatic hydrocarbon having a vinyl group are 4,4'-bis(2,2-diphenylvinyl)biphenyl (abbreviation: DPVBi), 9,10-bis[4-(2,2-diphenylvinyl)phenyl]anthracene (abbreviation: DPVPA), and the like.

Other examples are high molecular compounds such as poly(N-vinylcarbazole) (abbreviation: PVK), poly(4-vinyltriphenylamine) (abbreviation: PVTTPA), poly[N-(4-{N'-[4-(4-diphenylamino)phenyl]phenyl-N'-phenylamino}phenyl) methacrylamide] (abbreviation: PTPDMA), and poly[N,N'-bis(4-butylphenyl)-N,N'-bis(phenyl)benzidine] (abbreviation: poly-TPD).

Examples of the material having a high hole-transport property are aromatic amine compounds such as 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (abbreviation: NPB or α -NPB), N,N'-bis(3-methylphenyl)-N,N'-diphenyl-[1,1'-biphenyl]-4,4'-diamine (abbreviation: TPD), 4,4',4''-tris(carbazol-9-yl)triphenylamine (abbreviation: TCTA), 4,4',4''-tris[N-(1-naphthyl)-N-phenylamino]triphenylamine (abbreviation: 1'-TNATA), 4,4',4''-tris(N,N-diphenylamino)triphenylamine (abbreviation: TDATA), 4,4',4''-tris[N-(3-methylphenyl)-N-phenylamino]triphenylamine (abbreviation: MTDATA), 4,4'-bis[N-(spiro-9,9'-bifluorene-2-yl)-N-phenylamino]biphenyl (abbreviation: BSPB), 4-phenyl-4'-(9-phenylfluorene-9-yl)triphenylamine (abbreviation: BPAFLP), 4-phenyl-3'-(9-phenylfluorene-9-yl)triphenylamine (abbreviation: mBPAFLP), N-(9,9-dimethyl-9H-fluorene-2-yl)-N-{9,9-dimethyl-2-[N'-phenyl-N'-(9,9-dimethyl-9H-fluorene-2-yl)amino]-9H-fluorene-7-yl}phenylamine (abbreviation: DFLADFL), N-(9,9-dimethyl-2-diphenylamino-9H-fluorene-7-yl)diphenylamine (abbreviation: DPNF), 2-[N-(4-diphenylaminophenyl)-N-phenylamino]spiro-9,9'-bifluorene (abbreviation: DPASF), 4-phenyl-4'-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBA1BP), 4,4'-diphenyl-4''-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBB1BP), 4-(1-naphthyl)-4'-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBANB), 4,4'-di(1-naphthyl)-4''-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBNBB), 4-phenyldiphenyl-(9-phenyl-9H-carbazol-3-yl)amine (abbreviation: PCA1BP), N,N'-bis(9-phenylcarbazol-3-yl)-N,N'-diphenylbenzene-1,3-diamine (abbreviation: PCA2B), N,N',N''-triphenyl-N,N',N''-tris(9-phenylcarbazol-3-yl)benzene-1,3,5-triamine (abbreviation: PCA3B), N-(4-biphe-

nyl)-N-(9,9-dimethyl-9H-fluoren-2-yl)-9-phenyl-9H-carbazol-3-amine (abbreviation: PCBiF), N-(1,1'-biphenyl-4-yl)-N-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]-9,9-dimethyl-9H-fluoren-2-amine (abbreviation: PCBBiF), 9,9-dimethyl-N-phenyl-N-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]fluoren-2-amine (abbreviation: PCBAF), N-phenyl-N-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]spiro-9,9'-bifluoren-2-amine (abbreviation: PCBASF), 2-[N-(9-phenylcarbazol-3-yl)-N-phenylamino]spiro-9,9'-bifluorene (abbreviation: PCASF), 2,7-bis[N-(4-diphenylaminophenyl)-N-phenylamino]-spiro-9,9'-bifluorene (abbreviation: DPA2SF), N-[4-(9H-carbazol-9-yl)phenyl]-N-(4-phenyl)phenylaniline (abbreviation: YGA1BP), and N,N'-bis[4-(carbazol-9-yl)phenyl]-N,N'-diphenyl-9,9-dimethylfluorene-2,7-diamine (abbreviation: YGA2F). Other examples are amine compounds, carbazole compounds, thiophene compounds, furan compounds, fluorene compounds; triphenylene compounds; phenanthrene compounds, and the like such as 3-[4-(1-naphthyl)-phenyl]-9-phenyl-9H-carbazole (abbreviation: PCPN), 3-[4-(9-phenanthryl)-phenyl]-9-phenyl-9H-carbazole (abbreviation: PCPPn), 3,3'-bis(9-phenyl-9H-carbazole) (abbreviation: PCCP), 1,3-bis(N-carbazolyl)benzene (abbreviation: mCP), 3,6-bis(3,5-diphenylphenyl)-9-phenylcarbazole (abbreviation: CzTP), 3,6-di(9H-carbazol-9-yl)-9-phenyl-9H-carbazole (abbreviation: PhCzGI), 2,8-di(9H-carbazol-9-yl)-dibenzothiophene (abbreviation: Cz2DBT), 4-{3-[3-(9-phenyl-9H-fluoren-9-yl)phenyl]phenyl}dibenzofuran (abbreviation: mmDBFFLBI-II), 4,4',4''-(benzene-1,3,5-triyl)tri(dibenzofuran) (abbreviation: DBF3P-II), 1,3,5-tri(dibenzothiophen-4-yl)-benzene (abbreviated as DBT3P-II), 2,8-diphenyl-4-[4-(9-phenyl-9H-fluoren-9-yl)phenyl]dibenzothiophene (abbreviation: DBTFLP-III), 4-[4-(9-phenyl-9H-fluoren-9-yl)phenyl]-6-phenyldibenzothiophene (abbreviation: DBTFLP-IV), and 4-[3-(triphenyl-2-yl)phenyl]dibenzothiophene (abbreviation: mDBIPTp-II). Among the above compounds, compounds including a pyrrole skeleton, a furan skeleton, a thiophene skeleton, or an aromatic amine skeleton are preferred because of their high stability and reliability. In addition, the compounds having such skeletons have a high hole-transport property to contribute to a reduction in driving voltage.

As the guest material **142** (phosphorescent material), an iridium-, rhodium-, or platinum-based organometallic complex or metal complex can be used; in particular, an organoiridium complex such as an iridium-based ortho-metalated complex is preferable. As an ortho-metalated ligand, a 4H-triazole ligand, a 1H-triazole ligand, an imidazole ligand, a pyridine ligand, a pyrimidine ligand, a pyrazine ligand, an isoquinoline ligand, and the like can be given. As the metal complex, a platinum complex having a porphyrin ligand and the like can be given.

The organic compound **141_1**, the organic compound **141_2**, and the guest material **142** (phosphorescent material) are preferably selected such that the LUMO level of the guest material **142** (the phosphorescent material) is lower than that of the organic compound **141_1** and the HOMO level of the guest material **142** is lower than that of the organic compound **141_2**. With this structure, a light-emitting element with high emission efficiency and low driving voltage can be obtained.

Examples of the substance that has an emission peak in the blue or green wavelength range include organometallic iridium complexes having a 4H-triazole skeleton, such as tris{2-[5-(2-methylphenyl)-4-(2,6-dimethylphenyl)-4H-1,2,4-triazol-3-yl-κN2]phenyl-κC}iridium(III) (abbreviation: Ir(mpptz-dmp)₃), tris(5-methyl-3,4-diphenyl-4H-1,2,4-tri-

azolato)iridium(III) (abbreviation: Ir(Mptz)₃), tris[4-(3-biphenyl)-5-isopropyl-3-phenyl-4H-1,2,4-triazolato]iridium(III) (abbreviation: Ir(iPrptz-3b)₃), and tris[3-(5-biphenyl)-5-isopropyl-4-phenyl-4H-1,2,4-triazolato]iridium(III) (abbreviation: Ir(iPr5btz)₃); organometallic iridium complexes having a 1H-triazole skeleton, such as tris[3-methyl-1-(2-methylphenyl)-5-phenyl-1H-1,2,4-triazolato]iridium(III) (abbreviation: Ir(Mptz1-mp)₃) and tris(1-methyl-5-phenyl-3-propyl-1H-1,2,4-triazolato)iridium(III) (abbreviation: Ir(Prptz1-Me)₃); organometallic iridium complexes having an imidazole skeleton, such as fac-tris[1-(2,6-diisopropylphenyl)-2-phenyl-1H-imidazole]iridium(III) (abbreviation: Ir(iPrpmi)₃) and tris[3-(2,6-dimethylphenyl)-7-methylimidazo [1,2-f]phenanthridinato]iridium(III) (abbreviation: Ir(dmpimpt-Me)₃); and organometallic iridium complexes in which a phenylpyridine derivative having an electron-withdrawing group is a ligand, such as bis[2-(4',6'-difluorophenyl)pyridinato-N,C^{2'}]iridium(III) tetrakis(1-pyrazolyl)borate (abbreviation: FIr6), bis[2-(4',6'-difluorophenyl)pyridinato-N,C^{2'}]picolate (abbreviation: FIrpic), bis{2-[3',5'-bis(trifluoromethyl)phenyl]pyridinato-N,C^{2'}}iridium(III)picolate (abbreviation: Ir(CF₃ppy)₂(pic)), and bis[2-(4',6'-difluorophenyl)pyridinato-N,C^{2'}]iridium(III) acetylacetonate (abbreviation: FIr(acac)). Among the materials given above, the organic metal iridium complexes including a nitrogen-containing five-membered heterocyclic skeleton, such as a 4H-triazole skeleton, a 1H-triazole skeleton, or an imidazole skeleton have high triplet excitation energy, reliability, and emission efficiency and are thus especially preferable.

Examples of the substance that has an emission peak in the green or yellow wavelength range include organometallic iridium complexes having a pyrimidine skeleton, such as tris(4-methyl-6-phenylpyrimidinato)iridium(III) (abbreviation: Ir(mppm)₃), tris(4-t-butyl-6-phenylpyrimidinato)iridium(III) (abbreviation: Ir(tBuppm)₃), (acetylacetonato)bis(6-methyl-4-phenylpyrimidinato)iridium(III) (abbreviation: Ir(mppm)₂(acac)), (acetylacetonato)bis(6-tert-butyl-4-phenylpyrimidinato)iridium(III) (abbreviation: Ir(tBuppm)₂(acac)), (acetylacetonato)bis[4-(2-norbornyl)-6-phenylpyrimidinato]iridium(III) (abbreviation: Ir(nbppm)₂(acac)), (acetylacetonato)bis[5-methyl-6-(2-methylphenyl)-4-phenylpyrimidinato]iridium(III) (abbreviation: Ir(mppmm)₂(acac)), (acetylacetonato)bis{4,6-dimethyl-2-[6-(2,6-dimethylphenyl)-4-pyrimidinyl-κN3]phenyl-κC}iridium(III) (abbreviation: Ir(dmppm-dmp)₂(acac)), (acetylacetonato)bis(4,6-diphenylpyrimidinato)iridium(III) (abbreviation: Ir(dppm)₂(acac)); organometallic iridium complexes having a pyrazine skeleton, such as (acetylacetonato)bis(3,5-dimethyl-2-phenylpyrazinato)iridium(III) (abbreviation: Ir(mppr-Me)₂(acac)) and (acetylacetonato)bis(5-isopropyl-3-methyl-2-phenylpyrazinato)iridium(III) (abbreviation: Ir(mppr-iPr)₂(acac)); organometallic iridium complexes having a pyridine skeleton, such as tris(2-phenylpyridinato-N,C^{2'})iridium(III) (abbreviation: Ir(ppy)₃), bis(2-phenylpyridinato-N,C^{2'})iridium(III) acetylacetonate (abbreviation: Ir(ppy)₂(acac)), bis(benzo[h]quinolinato)iridium(III) acetylacetonate (abbreviation: Ir(bzq)₂(acac)), tris(benzo[h]quinolinato)iridium(III) (abbreviation: Ir(bzq)₃), tris(2-phenylquinolinato-N,C^{2'})iridium(III) (abbreviation: Ir(pq)₃), and bis(2-phenylquinolinato-N,C^{2'})iridium(III) acetylacetonate (abbreviation: Ir(pq)₂(acac)); organometallic iridium complexes such as bis(2,4-diphenyl-1,3-oxazolato-N,C^{2'})iridium(III)acetylacetonate (abbreviation: Ir(dpo)₂(acac)), bis{2-[4'-(perfluorophenyl)phenyl]pyridinato-N,C^{2'}}iridium(III)acetylacetonate (abbreviation: Ir(p-PF-ph)₂(acac)), and bis(2-phenylbenzothiazolato-N,

C^{2'})iridium(III)acetylacetonate (abbreviation: Ir(bt)₂(acac)); and a rare earth metal complex such as tris(acetylacetonato) (monophenanthroline)terbium(III) (abbreviation: Tb(acac)₃ (Phen)). Among the materials given above, the organometallic iridium complexes having a pyrimidine skeleton have

distinctively high reliability and light emission efficiency and are thus particularly preferable. Examples of the substance that has an emission peak in the yellow or red wavelength range include organometallic iridium complexes having a pyrimidine skeleton, such as (diisobutylmethanato)bis[4,6-bis(3-methylphenyl)pyrimidinato]iridium(III) (abbreviation: Ir(5mdppm)₂(dibm)), bis[4,6-bis(3-methylphenyl)pyrimidinato](dipivaloylmethanato)iridium(III) (abbreviation: Ir(5mdppm)₂(dpm)), and bis[4,6-di(naphthalen-1-yl)pyrimidinato](dipivaloylmethanato)iridium(III) (abbreviation: Ir(d1npm)₂(dpm)); organometallic iridium complexes having a pyrazine skeleton, such as (acetylacetonato)bis(2,3,5-triphenylpyrazinato)iridium(III) (abbreviation: Ir(tppr)₂(acac)), bis(2,3,5-triphenylpyrazinato) (dipivaloylmethanato)iridium(III) (abbreviation: Ir(tppr)₂(dpm)), and (acetylacetonato)bis[2,3-bis(4-fluorophenyl)quinoxalinato]iridium(III) (abbreviation: Ir(Fdpq)₂(acac)); organometallic iridium complexes having a pyridine skeleton, such as tris(1-phenylisoquinolinato-N, C^{2'})iridium(III) (abbreviation: Ir(piq)₃) and bis(1-phenylisoquinolinato-N, C^{2'})iridium(III)acetylacetonate (abbreviation: Ir(piq)₂(acac)); a platinum complex such as 2,3,7,8,12,13,17,18-octaethyl-21H,23H-porphyrin platinum(II) (abbreviation: PtOEP); and rare earth metal complexes such as tris(1,3-diphenyl-1,3-propanedionato)(monophenanthroline)europium(III) (abbreviation: Eu(DBM)₃(Phen)) and tris[1-(2-thenoyl)-3,3,3-trifluoroacetato](monophenanthroline)europium(III) (abbreviation: Eu(TTA)₃(Phen)). Among the materials given above, the organometallic iridium complexes having a pyrimidine skeleton have distinctively high reliability and light emission efficiency and are thus particularly preferable. Further, the organometallic iridium complexes having a pyrazine skeleton can provide red light emission with favorable chromaticity.

The above-described organometallic iridium complexes having a pyrimidine skeleton or a pyrazine skeleton have ligands with a high electron-accepting property and easily have a low LUMO level and thus are suitable for one embodiment of the present invention. Similarly, compounds (e.g., iridium complexes) with an electron-withdrawing group, such as a halogen group (e.g., a fluoro group) or a cyano group, easily have a low LUMO level and thus are suitable.

As the light-emitting material included in the light-emitting layer **130**, any material can be used as long as the material can convert the triplet excitation energy into light emission. As an example of the material that can convert the triplet excitation energy into light emission, a thermally activated delayed fluorescent (TADF) material can be given in addition to a phosphorescent material. Therefore, it is acceptable that the “phosphorescent material” in the description is replaced with the “thermally activated delayed fluorescence material”. Note that the thermally activated delayed fluorescence material is a material having a small difference between the triplet excitation energy level and the singlet excitation energy level and a function of converting triplet excitation energy into singlet excitation energy by reverse intersystem crossing. Thus, the TADF material can up-convert a triplet excited state into a singlet excited state (i.e., reverse intersystem crossing is possible) using a little thermal energy and efficiently exhibit light emission (fluorescence) from the singlet excited state. The TADF is

efficiently obtained under the condition where the difference in energy between the triplet excitation energy level and the singlet excitation energy level is preferably larger than 0 eV and smaller than or equal to 0.2 eV, further preferably larger than 0 eV and smaller than or equal to 0.1 eV.

In the case where the thermally activated delayed fluorescence material is composed of one kind of material, any of the following materials can be used, for example.

First, a fullerene, a derivative thereof, an acridine derivative such as proflavine, eosin, and the like can be given. Furthermore, a metal-containing porphyrin, such as a porphyrin containing magnesium (Mg), zinc (Zn), cadmium (Cd), tin (Sn), platinum (Pt), indium (In), or palladium (Pd), can be given. Examples of the metal-containing porphyrin include a protoporphyrin-tin fluoride complex (SnF₂(Proto IX)), a mesoporphyrin-tin fluoride complex (SnF₂(Meso IX)), a hematoporphyrin-tin fluoride complex (SnF₂(Hemato IX)), a coproporphyrin tetramethyl ester-tin fluoride complex (SnF₂(Copro III-4Me)), an octaethylporphyrin-tin fluoride complex (SnF₂(OEP)), an etioporphyrin-tin fluoride complex (SnF₂(Etio I)), and an octaethylporphyrin-platinum chloride complex (PtCl₂(OEP)).

As the thermally activated delayed fluorescence material composed of one kind of material, a heterocyclic compound including a π -electron rich heteroaromatic ring and a π -electron deficient heteroaromatic ring can also be used. Specifically, 2-(biphenyl-4-yl)-4,6-bis(12-phenylindolo[2,3-a]carbazol-11-yl)-1,3,5-triazine (abbreviation: PIC-TRZ), 2-{4-[3-(N-phenyl-9H-carbazol-3-yl)-9H-carbazol-9-yl]phenyl}-4,6-diphenyl-1,3,5-triazine (abbreviation: PCCzPTzn), 2-[4-(10H-phenoxazin-10-yl)phenyl]-4,6-diphenyl-1,3,5-triazine (abbreviation: PXZ-TRZ), 3-[4-(5-phenyl-5,10-dihydrophenazin-10-yl)phenyl]-4,5-diphenyl-1,2,4-triazole (abbreviation: PPZ-3TPT), 3-(9,9-dimethyl-9H-acridin-10-yl)-9H-xanthen-9-one (abbreviation: ACRXTN), bis[4-(9,9-dimethyl-9,10-dihydroacridine)phenyl]sulfone (abbreviation: DMAC-DPS), or 10-phenyl-10H,10'H-spiro[acridin-9,9'-anthracen]-10'-one (abbreviation: ACRSA) can be used. The heterocyclic compound is preferable because of having the π -electron rich heteroaromatic ring and the π -electron deficient heteroaromatic ring, for which the electron-transport property and the hole-transport property are high. Among skeletons having the π -electron deficient heteroaromatic ring, a diazine skeleton (a pyrimidine skeleton, a pyrazine skeleton, or a pyridazine skeleton) and a triazine skeleton have high stability and reliability and are particularly preferable. Among skeletons having the π -electron rich heteroaromatic ring, an acridine skeleton, a phenoxazine skeleton, a thiophene skeleton, a furan skeleton, and a pyrrole skeleton have high stability and reliability; therefore, one or more of these skeletons are preferably included. As the pyrrole skeleton, an indole skeleton, a carbazole skeleton, or a 3-(9-phenyl-9H-carbazol-3-yl)-9H-carbazole skeleton is particularly preferred. Note that a substance in which the π -electron rich heteroaromatic ring is directly bonded to the π -electron deficient heteroaromatic ring is particularly preferable because the donor property of the π -electron rich heteroaromatic ring and the acceptor property of the π -electron deficient heteroaromatic ring are both increased and the difference between the singlet excitation energy level and the triplet excitation energy level becomes small.

The light-emitting layer **140** can have a structure in which two or more layers are stacked. For example, in the case where the light-emitting layer **140** is formed by stacking a first light-emitting layer and a second light-emitting layer in this order from the hole-transport layer side, the first light-emitting layer is formed using a substance having a hole-

transport property as the host material and the second light-emitting layer is formed using a substance having an electron-transport property as the host material. A light-emitting material included in the first light-emitting layer may be the same as or different from a light-emitting material included in the second light-emitting layer. In addition, the materials may have functions of emitting light of the same color or light of different colors. Two kinds of light-emitting materials having functions of emitting light of different colors are used for the two light-emitting layers, so that light of a plurality of emission colors can be obtained at the same time. It is particularly preferable to select light-emitting materials of the light-emitting layers so that white light can be obtained by combining light emission from the two light-emitting layers.

The light-emitting layer **140** may include a material other than the host material **141** and the guest material **142**.

Note that the light-emitting layer **140** can be formed by an evaporation method (including a vacuum evaporation method), an inkjet method, a coating method, gravure printing, or the like. Besides the above-mentioned materials, an inorganic compound such as a quantum dot or a high molecular compound (e.g., an oligomer, a dendrimer, and a polymer) may be used.

<<Hole-Injection Layer>>

The hole-injection layer **111** has a function of reducing a barrier for hole injection from one of the pair of electrodes (the electrode **101** or the electrode **102**) to promote hole injection and is formed using a transition metal oxide, a phthalocyanine derivative, or an aromatic amine, for example. As the transition metal oxide, molybdenum oxide, vanadium oxide, ruthenium oxide, tungsten oxide, manganese oxide, or the like can be given. As the phthalocyanine derivative, phthalocyanine, metal phthalocyanine, or the like can be given. As the aromatic amine, a benzidine derivative, a phenylenediamine derivative, or the like can be given. It is also possible to use a high molecular compound such as polythiophene or polyaniline; a typical example thereof is poly(ethylenedioxythiophene)/poly(styrenesulfonic acid), which is self-doped polythiophene.

As the hole-injection layer **111**, a layer containing a composite material of a hole-transport material and a material having a property of accepting electrons from the hole-transport material can also be used. Alternatively, a stack of a layer containing a material having an electron accepting property and a layer containing a hole-transport material may also be used. In a steady state or in the presence of an electric field, electric charge can be transferred between these materials. As examples of the material having an electron-accepting property, organic acceptors such as a quinodimethane derivative, a chloranil derivative, and a hexaazatriphenylene derivative can be given. A specific example is a compound having an electron-withdrawing group (a halogen group or a cyano group), such as 7,7,8,8-tetracyano-2,3,5,6-tetrafluoroquinodimethane (abbreviation: F₄-TCNQ), chloranil, or 2,3,6,7,10,11-hexacyano-1,4,5,8,9,12-hexaazatriphenylene (abbreviation: HAT-CN). Alternatively, a transition metal oxide such as an oxide of a metal from Group 4 to Group 8 can also be used. Specifically, vanadium oxide, niobium oxide, tantalum oxide, chromium oxide, molybdenum oxide, tungsten oxide, manganese oxide, rhenium oxide, or the like can be used. In particular, molybdenum oxide is preferable because it is stable in the air, has a low hygroscopic property, and is easily handled.

A material having a property of transporting more holes than electrons can be used as the hole-transport material, and

a material having a hole mobility of 1×10^{-6} cm²/Vs or higher is preferable. Specifically, any of the aromatic amine, carbazole derivative, aromatic hydrocarbon, stilbene derivative, and the like described as examples of the hole-transport material that can be used in the light-emitting layer **140** can be used. Furthermore, the hole-transport material may be a high molecular compound.

Hole-Transport Layer>>

The hole-transport layer **112** is a layer containing a hole-transport material and can be formed using any of the hole-transport materials given as examples of the material of the hole-injection layer **111**. In order that the hole-transport layer **112** has a function of transporting holes injected into the hole-injection layer **111** to the light-emitting layer **140**, the HOMO level of the hole-transport layer **112** is preferably equal or close to the HOMO level of the hole-injection layer **111**.

As the hole-transport material, a substance having a hole mobility of 1×10^{-6} cm²/Vs or higher is preferably used.

Note that any substance other than the above substances may be used as long as the hole-transport property is higher than the electron-transport property. The layer including a substance having a high hole-transport property is not limited to a single layer, and two or more layers containing the aforementioned substances may be stacked.

<<Electron-Transport Layer>>

The electron-transport layer **118** has a function of transporting, to the light-emitting layer **130**, electrons injected from the other of the pair of electrodes (the electrode **101** or the electrode **102**) through the electron-injection layer **119**. A material having a property of transporting more electrons than holes can be used as the electron-transport material, and a material having an electron mobility of 1×10^{-6} cm²/Vs or higher is preferable. As the compound which easily accepts electrons (the material having an electron-transport property), a π -electron deficient heteroaromatic compound such as a nitrogen-containing heteroaromatic compound, a metal complex, or the like can be used, for example. Specifically, a metal complex having a quinoline ligand, a benzoquinoline ligand, an oxazole ligand, or a thiazole ligand, which are described as the electron-transport materials that can be used in the light-emitting layer **130**, can be given. In addition, an oxadiazole derivative, a triazole derivative, a benzimidazole derivative, a quinoxaline derivative, a dibenzoquinoxaline derivative, a phenanthroline derivative, a pyridine derivative, a bipyridine derivative, a pyrimidine derivative, and a triazine derivative can be given. A substance having an electron mobility of 1×10^{-6} cm²/Vs or higher is preferable. Note that other than these substances, any substance that has a property of transporting more electrons than holes may be used for the electron-transport layer. The electron-transport layer **118** is not limited to a single layer, and may include stacked two or more layers containing the aforementioned substances.

Between the electron-transport layer **118** and the light-emitting layer **140**, a layer that controls transfer of electron carriers may be provided. This is a layer formed by addition of a small amount of a substance having a high electron-trapping property to a material having a high electron-transport property described above, and the layer is capable of adjusting carrier balance by suppressing transfer of electron carriers. Such a structure is very effective in preventing a problem (such as a reduction in element lifetime) caused when electrons pass through the light-emitting layer.

<<Electron-Injection Layer>>

The electron-injection layer **119** has a function of reducing a barrier for electron injection from the electrode **102** to

promote electron injection and can be formed using a Group 1 metal or a Group 2 metal, or an oxide, a halide, or a carbonate of any of the metals, for example. Alternatively, a composite material containing an electron-transport material (described above) and a material having a property of donating electrons to the electron-transport material can also be used. As the material having an electron-donating property, a Group 1 metal, a Group 2 metal, an oxide of any of the metals, or the like can be given. Specifically, an alkali metal, an alkaline earth metal, or a compound thereof, such as lithium fluoride (LiF), sodium fluoride (NaF), cesium fluoride (CsF), calcium fluoride (CaF₂), or lithium oxide (LiO_x), can be used. Alternatively, a rare earth metal compound like erbium fluoride (ErF₃) can be used. Electride may also be used for the electron-injection layer **119**. Examples of the electride include a substance in which electrons are added at high concentration to calcium oxide-aluminum oxide. The electron-injection layer **119** can be formed using the substance that can be used for the electron-transport layer **118**.

A composite material in which an organic compound and an electron donor (donor) are mixed may also be used for the electron-injection layer **119**. Such a composite material is excellent in an electron-injection property and an electron-transport property because electrons are generated in the organic compound by the electron donor. In this case, the organic compound is preferably a material that is excellent in transporting the generated electrons. Specifically, the above-listed substances for forming the electron-transport layer **118** (e.g., the metal complexes and heteroaromatic compounds) can be used, for example. As the electron donor, a substance showing an electron-donating property with respect to the organic compound may be used. Specifically, an alkali metal, an alkaline earth metal, and a rare earth metal are preferable, and lithium, sodium, cesium, magnesium, calcium, erbium, and ytterbium are given. In addition, an alkali metal oxide or an alkaline earth metal oxide is preferable, and lithium oxide, calcium oxide, barium oxide, and the like are given. A Lewis base such as magnesium oxide can also be used. An organic compound such as tetrathiafulvalene (abbreviation: TTF) can also be used.

Note that the light-emitting layer, the hole-injection layer, the hole-transport layer, the electron-transport layer, and the electron-injection layer described above can each be formed by an evaporation method (including a vacuum evaporation method), an inkjet method, a coating method, a gravure printing method, or the like. Besides the above-mentioned materials, an inorganic compound such as a quantum dot or a high molecular compound (e.g., an oligomer, a dendrimer, and a polymer) may be used in the light-emitting layer, the hole-injection layer, the hole-transport layer, the electron-transport layer, and the electron-injection layer.

The quantum dot may be a colloidal quantum dot, an alloyed quantum dot, a core-shell quantum dot, or a core quantum dot, for example. The quantum dot containing elements belonging to Groups 2 and 16, elements belonging to Groups 13 and 15, elements belonging to Groups 13 and 17, elements belonging to Groups 11 and 17, or elements belonging to Groups 14 and 15 may be used. Alternatively, the quantum dot containing an element such as cadmium (Cd), selenium (Se), zinc (Zn), sulfur (S), phosphorus (P), indium (In), tellurium (Te), lead (Pb), gallium (Ga), arsenic (As), or aluminum (Al) may be used.

<<Pair of Electrodes>>

The electrodes **101** and **102** function as an anode and a cathode of each light-emitting element. The electrodes **101**

and **102** can be formed using a metal, an alloy, or a conductive compound, a mixture or a stack thereof, or the like.

One of the electrode **101** and the electrode **102** is preferably formed using a conductive material having a function of reflecting light. Examples of the conductive material include aluminum (Al), an alloy containing Al, and the like. Examples of the alloy containing Al include an alloy containing Al and L (L represents one or more of titanium (Ti), neodymium (Nd), nickel (Ni), and lanthanum (La)), such as an alloy containing Al and Ti and an alloy containing Al, Ni, and La. Aluminum has low resistance and high light reflectivity. Aluminum is included in earth's crust in large amount and is inexpensive; therefore, it is possible to reduce costs for manufacturing a light-emitting element with aluminum. Alternatively, Ag, an alloy of silver (Ag) and N (N represents one or more of yttrium (Y), Nd, magnesium (Mg), ytterbium (Yb), Al, Ti, gallium (Ga), zinc (Zn), indium (In), tungsten (W), manganese (Mn), tin (Sn), iron (Fe), Ni, copper (Cu), palladium (Pd), iridium (Ir), or gold (Au)), or the like can be used. Examples of the alloy containing silver include an alloy containing silver, palladium, and copper, an alloy containing silver and copper, an alloy containing silver and magnesium, an alloy containing silver and nickel, an alloy containing silver and gold, an alloy containing silver and ytterbium, and the like. Besides, a transition metal such as tungsten, chromium (Cr), molybdenum (Mo), copper, or titanium can be used.

Light emitted from the light-emitting layer is extracted through the electrode **101** and/or the electrode **102**. Thus, at least one of the electrode **101** and the electrode **102** is preferably formed using a conductive material having a function of transmitting light. As the conductive material, a conductive material having a visible light transmittance higher than or equal to 40% and lower than or equal to 100%, preferably higher than or equal to 60% and lower than or equal to 100%, and a resistivity lower than or equal to $1 \times 10^{-2} \Omega \cdot \text{cm}$ can be used.

The electrodes **101** and **102** may each be formed using a conductive material having functions of transmitting light and reflecting light. As the conductive material, a conductive material having a visible light reflectivity higher than or equal to 20% and lower than or equal to 80%, preferably higher than or equal to 40% and lower than or equal to 70%, and a resistivity lower than or equal to $1 \times 10^{-2} \Omega \cdot \text{cm}$ can be used. For example, one or more kinds of conductive metals and alloys, conductive compounds, and the like can be used. Specifically, a metal oxide such as indium tin oxide (hereinafter, referred to as ITO), indium tin oxide containing silicon or silicon oxide (ITSO), indium oxide-zinc oxide (indium zinc oxide), indium oxide-tin oxide containing titanium, indium titanium oxide, or indium oxide containing tungsten oxide and zinc oxide can be used. A metal thin film having a thickness that allows transmission of light (preferably, a thickness greater than or equal to 1 nm and less than or equal to 30 nm) can also be used. As the metal, Ag, an alloy of Ag and Al, an alloy of Ag and Mg, an alloy of Ag and Au, an alloy of Ag and ytterbium (Yb), or the like can be used.

In this specification and the like, as the material transmitting light, a material that transmits visible light and has conductivity is used. Examples of the material include, in addition to the above-described oxide conductor typified by an ITO, an oxide semiconductor and an organic conductor containing an organic substance. Examples of the organic conductive containing an organic substance include a composite material in which an organic compound and an

electron donor (donor material) are mixed and a composite material in which an organic compound and an electron acceptor (acceptor material) are mixed. Alternatively, an inorganic carbon-based material such as graphene may be used. The resistivity of the material is preferably lower than or equal to $1 \times 10^5 \Omega \cdot \text{cm}$, further preferably lower than or equal to $1 \times 10^4 \Omega \cdot \text{cm}$.

Alternatively, the electrode **101** and/or the electrode **102** may be formed by stacking two or more of these materials.

In order to improve the light extraction efficiency, a material whose refractive index is higher than that of an electrode having a function of transmitting light may be formed in contact with the electrode. The material may be electrically conductive or non-conductive as long as it has a function of transmitting visible light. In addition to the oxide conductors described above, an oxide semiconductor and an organic substance are given as the examples of the material. Examples of the organic substance include the materials for the light-emitting layer, the hole-injection layer, the hole-transport layer, the electron-transport layer, and the electron-injection layer. Alternatively, an inorganic carbon-based material or a metal film thin enough to transmit light can be used. Further alternatively, stacked layers with a thickness of several nanometers to several tens of nanometers may be used.

In the case where the electrode **101** or the electrode **102** functions as the cathode, the electrode preferably contains a material having a low work function (lower than or equal to 3.8 eV). The examples include an element belonging to Group 1 or 2 of the periodic table (e.g., an alkali metal such as lithium, sodium, or cesium, an alkaline earth metal such as calcium or strontium, or magnesium), an alloy containing any of these elements (e.g., Ag—Mg or Al—Li), a rare earth metal such as europium (Eu) or Yb, an alloy containing any of these rare earth metals, an alloy containing aluminum and silver, and the like.

When the electrode **101** or the electrode **102** is used as an anode, a material with a high work function (4.0 eV or higher) is preferably used.

The electrode **101** and the electrode **102** may be a stacked layer of a conductive material having a function of reflecting light and a conductive material having a function of transmitting light. In that case, the electrode **101** and the electrode **102** can have a function of adjusting the optical path length so that light with a desired wavelength emitted from each light-emitting layer resonates and is intensified, which is preferable.

As the method for forming the electrode **101** and the electrode **102**, a sputtering method, an evaporation method, a printing method, a coating method, a molecular beam epitaxy (MBE) method, a CVD method, a pulsed laser deposition method, an atomic layer deposition (ALD) method, or the like can be used as appropriate.

<<Substrate>>

A light-emitting element in one embodiment of the present invention may be formed over a substrate of glass, plastic, or the like. As the way of stacking layers over the substrate, layers may be sequentially stacked from the electrode **101** side or sequentially stacked from the electrode **102** side.

For the substrate over which the light-emitting element of one embodiment of the present invention can be formed, glass, quartz, plastic, or the like can be used, for example. Alternatively, a flexible substrate can be used. The flexible substrate means a substrate that can be bent, such as a plastic substrate made of polycarbonate or polyarylate, for example. Alternatively, a film, an inorganic vapor deposition film, or

the like can be used. Another material may be used as long as the substrate functions as a support in a manufacturing process of the light-emitting element or an optical element or as long as it has a function of protecting the light-emitting element or an optical element.

In this specification and the like, a light-emitting element can be formed using any of a variety of substrates, for example. The type of a substrate is not limited particularly. Examples of the substrate include a semiconductor substrate (e.g., a single crystal substrate or a silicon substrate), an SOI substrate, a glass substrate, a quartz substrate, a plastic substrate, a metal substrate, a stainless steel substrate, a substrate including stainless steel foil, a tungsten substrate, a substrate including tungsten foil, a flexible substrate, an attachment film, and paper which include a fibrous material, a base material film, and the like. As an example of a glass substrate, a barium borosilicate glass substrate, an aluminoborosilicate glass substrate, a soda lime glass substrate, and the like can be given. Examples of the flexible substrate, the attachment film, the base material film, and the like are substrates of plastics typified by polyethylene terephthalate (PET), polyethylene naphthalate (PEN), polyether sulfone (PES), and polytetrafluoroethylene (PTFE). Another example is a resin such as acrylic. Furthermore, polypropylene, polyester, polyvinyl fluoride, and polyvinyl chloride can be given as examples. Other examples are polyamide, polyimide, aramid, epoxy, an inorganic vapor deposition film, paper, and the like.

Alternatively, a flexible substrate may be used as the substrate such that the light-emitting element is provided directly on the flexible substrate. Further alternatively, a separation layer may be provided between the substrate and the light-emitting element. The separation layer can be used when part or the whole of a light-emitting element formed over the separation layer is separated from the substrate and transferred onto another substrate. In such a case, the light-emitting element can be transferred to a substrate having low heat resistance or a flexible substrate as well. For the above separation layer, a stack including inorganic films, which are a tungsten film and a silicon oxide film, or a structure in which a resin film of polyimide or the like is formed over a substrate can be used, for example.

In other words, after the light-emitting element is formed using a substrate, the light-emitting element may be transferred to another substrate. Example of the substrate to which the light-emitting element is transferred are, in addition to the above substrates, a cellophane substrate, a stone substrate, a wood substrate, a cloth substrate (including a natural fiber (e.g., silk, cotton, or hemp), a synthetic fiber (e.g., nylon, polyurethane, or polyester), a regenerated fiber (e.g., acetate, cupra, rayon, or regenerated polyester), and the like), a leather substrate, a rubber substrate, and the like. When such a substrate is used, a light-emitting element with high durability, high heat resistance, reduced weight, or reduced thickness can be formed.

The light-emitting element **152** may be formed over an electrode electrically connected to a field-effect transistor (FET), for example, that is formed over any of the above-described substrates. Accordingly, an active matrix display device in which the FET controls the driving of the light-emitting element **152** can be manufactured.

In this embodiment, one embodiment of the present invention has been described. Other embodiments of the present invention are described in other embodiments. Note that one embodiment of the present invention is not limited thereto. That is, since various embodiments of the present invention are disclosed in this embodiment and other

embodiments, one embodiment of the present invention is not limited to a specific embodiment. The example in which one embodiment of the present invention is used in a light-emitting element is described; however, one embodiment of the present invention is not limited thereto. For example, depending on circumstances or conditions, one embodiment of the present invention is not necessarily used in a light-emitting element. One embodiment of the present invention shows, but is not limited to, an example of containing a first organic compound, a second organic compound, and a guest material capable of converting triplet excitation energy into light emission, in which the LUMO level of the first organic compound is lower than that of the second organic compound and the HOMO level of the first organic compound is lower than that of the second organic compound. Depending on circumstances or conditions, in one embodiment of the present invention, for example, the LUMO level of the first organic compound is not necessarily lower than that of the second organic compound. Alternatively, the HOMO level of the first organic compound is not necessarily lower than that of the second organic compound. One embodiment of the present invention shows, but is not limited to, an example in which the first organic compound and the second organic compound form an exciplex. Depending on circumstances or conditions, in one embodiment of the present invention, for example, the first organic compound and the second organic compound do not necessarily form an exciplex. One embodiment of the present invention shows, but is not limited to, an example in which the LUMO level of the guest material is higher than that of the first organic compound and the HOMO level of the guest material is lower than that of the second organic compound. Depending on circumstances or conditions, in one embodiment of the present invention, for example, the LUMO level of the guest material is not necessarily higher than that of the first organic compound. Alternatively, the HOMO level of the guest material is not necessarily lower than that of the second organic compound.

The structure described in this embodiment can be used in combination with any of the structures described in the other embodiments as appropriate.

EMBODIMENT 2

In this embodiment, a light-emitting element having a structure different from that described in Embodiment 1 and light emission mechanisms of the light-emitting element are described below with reference to FIGS. 3A to 3C and FIGS. 4A to 4C. In FIGS. 3A to 3C and FIGS. 4A to 4C, a portion having a function similar to that in FIG. 1A is represented by the same hatch pattern as in FIG. 1A and not especially denoted by a reference numeral in some cases. In addition, common reference numerals are used for portions having similar functions, and a detailed description of the portions is omitted in some cases.

STRUCTURE EXAMPLE 1 OF LIGHT-EMITTING ELEMENT

FIG. 3A is a schematic cross-sectional view of a light-emitting element 250.

The light-emitting element 250 illustrated in FIG. 3A includes a plurality of light-emitting units (a light-emitting unit 106 and a light-emitting unit 108 in FIG. 3A) between a pair of electrodes (the electrode 101 and the electrode 102). One of light-emitting units preferably has the same structure as the EL layer 100 illustrated in FIGS. 1A and 1B.

That is, it is preferable that the light-emitting element 152 in FIGS. 1A and 1B include one light-emitting unit, while the light-emitting element 250 include a plurality of light-emitting units. Note that the electrode 101 functions as an anode and the electrode 102 functions as a cathode in the following description of the light-emitting element 250; however, the functions may be interchanged in the light-emitting element 250.

In the light-emitting element 250 illustrated in FIG. 3A, the light-emitting unit 106 and the light-emitting unit 108 are stacked, and a charge-generation layer 115 is provided between the light-emitting unit 106 and the light-emitting unit 108. Note that the light-emitting unit 106 and the light-emitting unit 108 may have the same structure or different structures. For example, it is preferable that the EL layer 100 illustrated in FIGS. 1A and 1B be used in the light-emitting unit 108.

The light-emitting element 250 includes a light-emitting layer 120 and a light-emitting layer 170. The light-emitting unit 106 includes the hole-injection layer 111, the hole-transport layer 112, an electron-transport layer 113, and an electron-injection layer 114 in addition to the light-emitting layer 120. The light-emitting unit 108 includes a hole-injection layer 116, a hole-transport layer 117, an electron-transport layer 118, and an electron-injection layer 119 in addition to the light-emitting layer 170.

The charge-generation layer 115 may have either a structure in which an acceptor substance that is an electron acceptor is added to a hole-transport material or a structure in which a donor substance that is an electron donor is added to an electron-transport material. Alternatively, both of these structures may be stacked.

In the case where the charge-generation layer 115 contains a composite material of an organic compound and an acceptor substance, the composite material that can be used for the hole-injection layer 111 described in Embodiment 1 may be used for the composite material. As the organic compound, a variety of compounds such as an aromatic amine compound, a carbazole compound, an aromatic hydrocarbon, and a high molecular compound (such as an oligomer, a dendrimer, or a polymer) can be used. An organic compound having a hole mobility of $1 \times 10^{-6} \text{ cm}^2/\text{Vs}$ or higher is preferably used as the organic compound. Note that any other material may be used as long as it has a property of transporting more holes than electrons. Since the composite material of an organic compound and an acceptor substance has excellent carrier-injection and carrier-transport properties, low-voltage driving or low-current driving can be realized. Note that when a surface of a light-emitting unit on the anode side is in contact with the charge-generation layer 115 like the light-emitting unit 108, the charge-generation layer 115 can also serve as a hole-injection layer or a hole-transport layer of the light-emitting unit; thus, a hole-injection layer or a hole-transport layer need not be included in the light-emitting unit.

The charge-generation layer 115 may have a stacked structure of a layer containing the composite material of an organic compound and an acceptor substance and a layer containing another material. For example, the charge-generation layer 115 may be formed using a combination of a layer containing the composite material of an organic compound and an acceptor substance with a layer containing one compound selected from among electron-donating materials and a compound having a high electron-transport property. Furthermore, the charge-generation layer 115 may be formed using a combination of a layer containing the

composite material of an organic compound and an acceptor substance with a layer containing a transparent conductive material.

Note that the charge-generation layer **115** provided between the light-emitting unit **106** and the light-emitting unit **108** may have any structure as long as electrons can be injected to the light-emitting unit on one side and holes can be injected into the light-emitting unit on the other side when a voltage is applied between the electrode **101** and the electrode **102**. For example, in FIG. 3A, the charge-generation layer **115** injects electrons into the light-emitting unit **106** and holes into the light-emitting unit **108** when a voltage is applied such that the potential of the electrode **101** is higher than that of the electrode **102**.

Note that in terms of light extraction efficiency, the charge-generation layer **115** preferably has a visible light transmittance (specifically, a visible light transmittance of higher than or equal to 40%). The charge-generation layer **115** functions even if it has lower conductivity than the pair of electrodes (the electrodes **101** and **102**).

Forming the charge-generation layer **115** by using any of the above materials can suppress an increase in drive voltage caused by the stack of the light-emitting layers.

The light-emitting element having two light-emitting units has been described with reference to FIG. 3A; however, a similar structure can be applied to a light-emitting element in which three or more light-emitting units are stacked. With a plurality of light-emitting units partitioned by the charge-generation layer between a pair of electrodes as in the light-emitting element **250**, it is possible to provide a light-emitting element which can emit light with high luminance with the current density kept low and has a long lifetime. A light-emitting element with low power consumption can be provided.

When the structures described in Embodiment 1 is used for at least one of the plurality of units, a light-emitting element with high emission efficiency can be provided.

It is preferable that the light-emitting layer **170** of the light-emitting unit **108** have a structure similar to that of the light-emitting layer **140** described in Embodiment 1, in which case the light-emitting element **250** has high emission efficiency.

The light-emitting layer **120** included in the light-emitting unit **106** contains a host material **121** and a guest material **122** as illustrated in FIG. 3B. Note that the guest material **122** is described below as a fluorescent material.

<<Light Emission Mechanism of Light-Emitting Layer **120**>>

The light emission mechanism of the light-emitting layer **120** is described below.

By recombination of the electrons and holes injected from the pair of electrodes (the electrode **101** and the electrode **102**) or the charge-generation layer in the light-emitting layer **120**, excitons are formed. Because the amount of the host material **121** is larger than that of the guest material **122**, the host material **121** is brought into an excited state by the exciton generation.

Note that the term “exciton” refers to a carrier (electron and hole) pair. Since excitons have energy, a material where excitons are generated is brought into an excited state.

In the case where the formed excited state of the host material **121** is a singlet excited state, singlet excitation energy transfers from the S1 level of the host material **121** to the S1 level of the guest material **122**, thereby forming the singlet excited state of the guest material **122**.

Since the guest material **122** is a fluorescent material, when a singlet excited state is formed in the guest material

122, the guest material **122** immediately emits light. To obtain high light emission efficiency in this case, the fluorescence quantum yield of the guest material **122** is preferably high. The same can apply to a case where a singlet excited state is formed by recombination of carriers in the guest material **122**.

Next, a case where recombination of carriers forms a triplet excited state of the host material **121** is described. The correlation of energy levels of the host material **121** and the guest material **122** in this case is shown in FIG. 3C. The following explains what terms and signs in FIG. 3C represent. Note that because it is preferable that the T1 level of the host material **121** be lower than the T1 level of the guest material **122**, FIG. 3C shows this preferable case. However, the T1 level of the host material **121** may be higher than the T1 level of the guest material **122**.

Host (**121**): the host material **121**;

Guest (**122**): the guest material **122** (the fluorescent material);

S_{FH} : the S1 level the host material **121**;

T_{FH} : the T1 level of the host material **121**;

S_{FG} : the S1 level of the guest material **122** (the fluorescent material); and

T_{FG} : the T1 level of the guest material **122** (the fluorescent material).

As illustrated in FIG. 3C, triplet-triplet annihilation (TTA) occurs, that is, triplet excitons formed by carrier recombination interact with each other, and excitation energy is transferred and spin angular momenta are exchanged; as a result, a reaction in which the triplet excitons are converted into singlet exciton having energy of the S1 level of the host material **121** (S_{FR}) (see TTA in FIG. 3C). The singlet excitation energy of the host material **121** is transferred from S_{FH} to the S1 level of the guest material **122** (S_{FG}) having a lower energy than S_{FH} (see Route E_1 in FIG. 3C), and a singlet excited state of the guest material **122** is formed, whereby the guest material **122** emits light.

Note that in the case where the density of triplet excitons in the light-emitting layer **120** is sufficiently high (e.g., $1 \times 10^{-12} \text{ cm}^{-3}$ or higher), only the reaction of two triplet excitons close to each other can be considered whereas deactivation of a single triplet exciton can be ignored.

In the case where a triplet excited state of the guest material **122** is formed by carrier recombination, the triplet excited state of the guest material **122** is thermally deactivated and is difficult to use for light emission. However, in the case where the T1 level of the host material **121** (T_{FH}) is lower than the T1 level of the guest material **122** (T_{FG}), the triplet excitation energy of the guest material **122** can be transferred from the T1 level of the guest material **122** (T_{FG}) to the T1 level of the host material **121** (T_{FH}) (see Route E_2 in FIG. 3C) and then is utilized for TTA.

In other words, the host material **121** preferably has a function of converting triplet excitation energy into singlet excitation energy by causing TTA, so that the triplet excitation energy generated in the light-emitting layer **120** can be partly converted into singlet excitation energy by TTA in the host material **121**. The singlet excitation energy can be transferred to the guest material **122** and extracted as fluorescence. In order to achieve this, the S1 level of the host material **121** (S_{FH}) is preferably higher than the S1 level of the guest material **122** (S_{FG}). In addition, the T1 level of the host material **121** (T_{FH}) is preferably lower than the T1 level of the guest material **122** (T_{FG}).

Note that particularly in the case where the T1 level of the guest material **122** (T_{FG}) is lower than the T1 level of the host material **121** (T_{FH}), the weight ratio of the guest

material **122** to the host material **121** is preferably low. Specifically, the weight ratio of the guest material **122** to the host material **121** is preferably greater than 0 and less than or equal to 0.05, in which case the probability of carrier recombination in the guest material **122** can be reduced. In addition, the probability of energy transfer from the T1 level of the host material **121** (T_{FH}) to the T1 level of the guest material **122** (T_{FG}) can be reduced.

Note that the host material **121** may be composed of a single compound or a plurality of compounds.

Note that in each of the above-described structures, emission colors of guest materials used in the light-emitting unit **106** and the light-emitting unit **108** may be the same or different. In the case where the same guest materials emitting light of the same color are used for the light-emitting unit **106** and the light-emitting unit **108**, the light-emitting element **250** can exhibit high emission luminance at a small current value, which is preferable. In the case where guest materials emitting light of different colors are used for the light-emitting unit **106** and the light-emitting unit **108**, the light-emitting element **250** can exhibit multi-color light emission, which is preferable. In that case, when a plurality of light-emitting materials with different emission wavelengths are used in one or both of the light-emitting layers **120** and **170**, lights with different emission peaks synthesize light emission from the light-emitting element **250**. That is, the emission spectrum of the light-emitting element **250** has at least two maximum values.

The above-described structure is also suitable for obtaining white light emission. When the light-emitting layer **120** and the light-emitting layer **170** emit light of complementary colors, white light emission can be obtained. It is particularly favorable to select the guest materials so that white light emission with high color rendering properties or light emission of at least red, green, and blue can be obtained.

One or both of the light-emitting layers **120** and **170** may be divided into layers and each of the divided layers may contain a different light-emitting material. That is, one or both of the light-emitting layers **120** and **170** may consist of two or more layers. For example, in the case where the light-emitting layer is formed by stacking a first light-emitting layer and a second light-emitting layer in this order from the hole-transport layer side, the first light-emitting layer is formed using a substance having a hole-transport property as the host material and the second light-emitting layer is formed using a substance having an electron-transport property as the host material. In that case, a light-emitting material included in the first light-emitting layer may be the same as or different from a light-emitting material included in the second light-emitting layer. In addition, the materials may have functions of emitting light of the same color or light of different colors. White light emission with a high color rendering property that is formed of three primary colors or four or more colors can be obtained by using a plurality of light-emitting materials emitting light of different colors.

In the case where the light-emitting units **106** and **108** contain guest materials with different colors, light emitted from the light-emitting layer **120** preferably has a peak on the shorter wavelength side than light emitted from the light-emitting layer **170**. Since the luminance of a light-emitting element using a material having a high triplet excited energy level tends to be degraded quickly, TTA is utilized in the light-emitting layer emitting light with a short

wavelength so that a light-emitting element with less degradation of luminance can be provided.

STRUCTURE EXAMPLE 2 OF LIGHT-EMITTING ELEMENT

Next, a structure example different from the light-emitting element illustrated in FIGS. **3A** to **3C** are described below with reference to FIGS. **4A** to **4C**.

FIG. **4A** is a schematic cross-sectional view of a light-emitting element **252**.

In the light-emitting element **252** shown in FIG. **4A**, an EL layer **110** is between a pair of electrodes (an electrode **101** and an electrode **102**). Although the electrode **101** functions as an anode and the electrode **102** functions as a cathode in the following description of the light-emitting element **252**, the functions may be interchanged in the light-emitting element **252**.

The EL layer **110** includes a light-emitting layer **180**. The light-emitting layer **180** includes the light-emitting layer **120** and the light-emitting layer **170**. Although the EL layer **110** also includes a hole-injection layer **111**, a hole-transport layer **112**, an electron-transport layer **118**, and an electron-injection layer **119**, this stacked-layer structure is one example and thus the structure of the EL layer **110** in the light-emitting element **252** is not limited thereto. For example, the stacking order of these layers of the EL layer **110** may be changed or another functional layer may be provided in the EL layer **110**. The functional layer may have a function of lowering a hole- or electron-injection barrier, a function of improving a hole- or electron-transport property, a function of inhibiting transport of holes or electrons, or a function of producing holes or electrons, for example.

As illustrated in FIG. **4B**, the light-emitting layer **120** contains the host material **121** and the guest material **122**. The light-emitting layer **170** contains a host material **171** and a guest material **172**. The host material **171** contains an organic compound **171_1** and an organic compound **171_2**. Note that in the description below, the guest material **122** is a fluorescent material and the guest material **172** is a phosphorescent material.

<<Light Emission Mechanism of Light-Emitting Layer **180**>>

The light emission mechanism of the light-emitting layer **120** is similar to that of the light-emitting layer **120** illustrated in FIGS. **3A** to **3C**. The light-emitting mechanism of the light-emitting layer **170** is similar to that of the light-emitting layer **140** in Embodiment 1. In other words, the host material **171**, the organic compound **171_1**, the organic compound **171_2**, and the guest material **172** are similar to the host material **141**, the guest material **142**, the organic compound **141_1**, and the organic compound **141_2**.

As in the light-emitting element **252**, in the case where the light-emitting layers **120** and **170** are in contact with each other, even when energy is transferred from the exciplex to the host material **121** of the light-emitting layer **120** (in particular, when energy of the triplet excited level is transferred) at an interface between the light-emitting layer **120** and the light-emitting layer **170**, triplet excitation energy can be converted into light emission in the light-emitting layer **120**.

The T1 level of the host material **121** of the light-emitting layer **120** is preferably lower than T1 levels of the organic compounds **171_1** and **171_2** of the light-emitting layer **170**. In the light-emitting layer **120**, an S1 level of the host material **121** is preferably higher than an S1 level of the guest material **122** (the fluorescent material) while the T1

level of the host material **121** is preferably lower than the T1 level of the guest material **122** (the fluorescent material).

FIG. 4C shows a correlation of energy levels in the case where TTA is utilized in the light-emitting layer **120** and ExTET is utilized in the light-emitting layer **170**. The following explains what terms and signs in FIG. 4C represent:

Fluorescence EML (**120**): the light-emitting layer **120** (the fluorescent light-emitting layer);

Phosphorescence EML (**170**): the light-emitting layer **170** (the phosphorescent light-emitting layer);

Host (**121**): the host material **121**;

Guest (**122**): the guest material **122** (the fluorescent material);

Host (**171_1**): a host material (the organic compound **171_1**);

Guest (**172**): the guest material **172** (the phosphorescent material);

Exciplex: an exciplex (the organic compound **171_1** and the organic compound **171_2**);

S_{FH} : the S1 level of the host material **121**;

T_{FH} : the T1 level of the host material **121**;

S_{FG} : the S1 level of the guest material **122** (the fluorescent material);

T_{FG} : the T1 level of the guest material **122** (the fluorescent material);

S_{PH} : the S1 level of the organic compound **171_1** (the host material);

T_{PH} : the T1 level of the organic compound **171_1** (the host material);

T_{PG} : the T1 level of the guest material **172** (the phosphorescent material);

S_E : the S1 level of the exciplex; and

T_E : the T1 level of the exciplex.

As shown in FIG. 4C, the exciplex exists only in an excited state; thus, exciton diffusion between the exciplexes is less likely to occur. In addition, because the excited energy levels of the exciplex (S_E and T_E) are lower than the excited energy levels of the organic compound **171_1** (the host material of the phosphorescent material) of the light-emitting layer **170** (S_{PH} and T_{PH}), energy diffusion from the exciplex to the organic compound **171_1** does not occur. That is, emission efficiency of the phosphorescent light-emitting layer (the light-emitting layer **170**) can be maintained because an exciton diffusion distance of the exciplex is short in the phosphorescent light-emitting layer (the light-emitting layer **170**). In addition, even when part of the triplet excitation energy of the exciplex of the phosphorescent light-emitting layer (the light-emitting layer **170**) diffuses into the fluorescent light-emitting layer (the light-emitting layer **120**) through the interface between the fluorescent light-emitting layer (the light-emitting layer **120**) and the phosphorescent light-emitting layer (the light-emitting layer **170**), energy loss can be reduced because the triplet excitation energy in the fluorescent light-emitting layer (the light-emitting layer **120**) caused by the diffusion is converted into light emission through TTA.

The light-emitting element **252** can have high emission efficiency because ExTET is utilized in the light-emitting layer **170** and TTA is utilized in the light-emitting layer **120** as described above so that energy loss is reduced. As in the light-emitting element **252**, in the case where the light-emitting layer **120** and the light-emitting layer **170** are in contact with each other, the number of EL layers **110** as well as the energy loss can be reduced. Therefore, a light-emitting element with low manufacturing cost can be obtained.

Note that the light-emitting layer **120** and the light-emitting layer **170** are not necessarily in contact with each other. In that case, it is possible to prevent energy transfer by the Dexter mechanism (particularly triplet energy transfer) from organic compounds **171_1** and **171_2** in an excited state or the guest material **172** (the phosphorescent material) in an excited state which is generated in the light-emitting layer **170** to the host material **121** or the guest material **122** (the fluorescent material) in the light-emitting layer **120**. Therefore, the thickness of a layer provided between the light-emitting layer **120** and the light-emitting layer **170** needs several nanometers; specifically, the thickness is preferably more than or equal to 1 nm and less than or equal to 5 nm, in which case an increase in driving voltage can be suppressed.

The layer provided between the light-emitting layer **120** and the light-emitting layer **170** may contain a single material or both a hole-transport material and an electron-transport material. In the case of a single material, a bipolar material may be used. The bipolar material here refers to a material in which the ratio between the electron mobility and the hole mobility is 100 or less. Alternatively, the hole-transport material, the electron-transport material, or the like may be used. At least one of materials contained in the layer may be the same as the host material (the organic compound **171_1** or **171_2**) of the light-emitting layer **170**. This facilitates the manufacture of the light-emitting element and reduces the drive voltage. Furthermore, the hole-transport material and the electron-transport material may form an exciplex, which effectively prevents exciton diffusion. Specifically, it is possible to prevent energy transfer from the host material (the organic compound **171_1** or **171_2**) in an excited state or the guest material **172** (the phosphorescent material) in an excited state of the light-emitting layer **170** to the host material **121** or the guest material **122** (the fluorescent material) in the light-emitting layer **120**.

In the light-emitting element **252**, although the light-emitting layer **120** and the light-emitting layer **170** have been described as being positioned on the hole-transport layer **112** side and the electron-transport layer **118** side, respectively, the light-emitting element of one embodiment of the present invention is not limited to this structure. For example, the light-emitting layer **120** and the light-emitting layer **170** may be positioned on the electron-transport layer **118** side and the hole-transport layer **112** side, respectively.

Note that in the light-emitting element **252**, a carrier recombination region is preferably distributed to some extent. Therefore, it is preferable that the light-emitting layer **120** or **170** have an appropriate degree of carrier-trapping property. It is particularly preferable that the guest material **172** (the phosphorescent material) in the light-emitting layer **170** have an electron-trapping property. Thus, the light-emitting layer **170** preferably has the structure of the light-emitting layer **140** in Embodiment 1.

Note that light emitted from the light-emitting layer **120** preferably has a peak on the shorter wavelength side than light emitted from the light-emitting layer **170**. The luminance of a light-emitting element using the phosphorescent material emitting light with a short wavelength tends to degrade quickly. In view of the above, fluorescence is used for light emission with a short wavelength, so that a light-emitting element with less degradation of luminance can be provided.

Furthermore, the light-emitting layers **120** and **170** are made to emit light with different emission wavelengths, so that the light-emitting element can be a multicolor light-emitting element. In that case, the emission spectrum is

formed by combining light having different emission peaks, and thus has at least two peaks.

The above-described structure is suitable for obtaining white light emission. When the light-emitting layers **120** and **170** emit light of complementary colors, white light emission can be obtained.

In addition, white light emission with a high color rendering property that is formed of three primary colors or four or more colors can be obtained by using a plurality of light-emitting substances emitting light with different wavelengths for one or both of the light-emitting layers **120** and **170**. In that case, the light-emitting layer **120** may be divided into layers and each of the divided layers may contain a different light-emitting material from the others.

<Material that can be Used in Light-Emitting Layers>

Next, materials that can be used in the light-emitting layers **120** and **170** are described.

<<Material that can be Used in Light-Emitting Layer **120**>>

In the light-emitting layer **120**, the host material **121** is present in the highest proportion by weight, and the guest material **122** (the fluorescent material) is dispersed in the host material **121**. The S1 level of the host material **121** is preferably higher than the S1 level of the guest material **122** (the fluorescent material) while the T1 level of the host material **121** is preferably lower than the T1 level of the guest material **122** (the fluorescent material).

In the light-emitting layer **120**, the guest material **122** is preferably, but not particularly limited to, an anthracene derivative, a tetracene derivative, a chrysene derivative, a phenanthrene derivative, a pyrene derivative, a perylene derivative, a stilbene derivative, an acridone derivative, a coumarin derivative, a phenoxazine derivative, a phenothiazine derivative, or the like, and for example, any of the following materials can be used.

The examples include 5,6-bis[4-(10-phenyl-9-anthryl)phenyl]-2,2'-bipyridine (abbreviation: PAP2BPy), 5,6-bis[4'-(10-phenyl-9-anthryl)biphenyl-4-yl]-2,2'-bipyridine (abbreviation: PAPP2BPy), N,N'-diphenyl-N,N'-bis[4-(9-phenyl-9H-fluoren-9-yl)phenyl]pyrene-1,6-diamine (abbreviation: 1,6FLPAPm), N,N'-bis(3-methylphenyl)-N,N'-bis[3-(9-phenyl-9H-fluoren-9-yl)phenyl]pyrene-1,6-diamine (abbreviation: 1,6mMemFLPAPm), N,N'-bis[4-(9-phenyl-9H-fluoren-9-yl)phenyl]-N,N'-bis(4-tert-butylphenyl)pyrene-1,6-diamine (abbreviation: 1,6tBuFLPAPm), N,N'-diphenyl-N,N'-bis[4-(9-phenyl-9H-fluoren-9-yl)phenyl]-3,8-dicyclohexylpyrene-1,6-diamine (abbreviation: ch-1,6FLPAPm), N,N'-bis[4-(9H-carbazol-9-yl)phenyl]diphenylstilbene-4,4'-diamine (abbreviation: YGA2S), 4-(9H-carbazol-9-yl)-4'-(10-phenyl-9-anthryl)triphenylamine (abbreviation: YGAPA), 4-(9H-carbazol-9-yl)-4'-(9,10-diphenyl-2-anthryl)triphenylamine (abbreviation: 2YGAPPA), N,9-diphenyl-N-[4-(10-phenyl-9-anthryl)phenyl]-9H-carbazol-3-amine (abbreviation: PCAPA), perylene, 2,5,8,11-tetra(tert-butyl)perylene (abbreviation: TBP), 4-(10-phenyl-9-anthryl)-4'-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBAPA), N,N'-(2-tert-butylanthracene-9,10-diyl)-4,1-phenylenebis[N,N',N'-triphenyl-1,4-phenylenediamine] (abbreviation: DPABPA), N,9-diphenyl-N-[4-(9,10-diphenyl-2-anthryl)phenyl]-9H-carbazol-3-amine (abbreviation: 2PCAPPA), N-[4-(9,10-diphenyl-2-anthryl)phenyl]-N,N',N'-triphenyl-1,4-phenylenediamine (abbreviation: 2DPAPPA), N,N,N',N',N'',N''',N''''-octaphenyldibenzo[g,p]chrysene-2,7,10,15-tetraamine (abbreviation: DBC1), coumarin 30, N-(9,10-diphenyl-2-anthryl)-N,9-diphenyl-9H-carbazol-3-amine (abbreviation: 2PCAPA), N-[9,10-bis(1,1'-biphenyl-2-yl)-2-anthryl]-N,9-diphenyl-9H-carbazol-3-amine (abbreviation: 2PCABPhA),

N-(9,10-diphenyl-2-anthryl)-N,N',N'-triphenyl-1,4-phenylenediamine (abbreviation: 2DPAPA), N-[9,10-bis(1,1'-biphenyl-2-yl)-2-anthryl]-N,N',N'-triphenyl-1,4-phenylenediamine (abbreviation: 2DPABPhA), 9,10-bis(1,1'-biphenyl-2-yl)-N-[4-(9H-carbazol-9-yl)phenyl]-N-phenylanthracene-2-amine (abbreviation: 2YGABPhA), N,N,9-triphenylanthracene-9-amine (abbreviation: DPhAPhA), coumarin 6, coumarin 545T, N,N'-diphenylquinacridone (abbreviation: DPQd), rubrene, 2,8-di-tert-butyl-5,11-bis(4-tert-butylphenyl)-6,12-diphenyltetracene (abbreviation: TBRb), Nile red, 5,12-bis(1,1'-biphenyl-4-yl)-6,11-diphenyltetracene (abbreviation: BPT), 2-(2-{2-[4-(dimethylamino)phenyl]ethenyl}-6-methyl-4H-pyran-4-ylidene)propanedinitrile (abbreviation: DCM1), 2-{2-methyl-6-[2-(2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene}propanedinitrile (abbreviation: DCM2), N,N,N',N'-tetrakis(4-methylphenyl)tetracene-5,11-diamine (abbreviation: p-mPhTD), 7,14-diphenyl-N,N,N',N'-tetrakis(4-methylphenyl)acenaphtho[1,2-a]fluoranthene-3,10-diamine (abbreviation: p-mPhAFD), 2-{2-isopropyl-6-[2-(1,1,7,7-tetramethyl-2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene}propanedinitrile (abbreviation: DCJT1), 2-{2-tert-butyl-6-[2-(1,1,7,7-tetramethyl-2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene}propanedinitrile (abbreviation: DCJTb), 2-(2,6-bis{2-[4-(dimethylamino)phenyl]ethenyl}-4H-pyran-4-ylidene)propanedinitrile (abbreviation: BisDCM), 2-{2,6-bis[2-(8-methoxy-1,1,7,7-tetramethyl-2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene}propanedinitrile (abbreviation: BisDCJTM), and 5,10,15,20-tetraphenylbisbenzo[5,6]indeno[1,2,3-cd:1',2',3'-lm]perylene.

Although there is no particular limitation on a material that can be used as the host material **121** in the light-emitting layer **120**, any of the following materials can be used, for example: metal complexes such as tris(8-quinolinolato)aluminum(III) (abbreviation: Alq), tris(4-methyl-8-quinolinolato)aluminum(III) (abbreviation: Almq₃), bis(10-hydroxybenzo[h]quinolinato)beryllium(II) (abbreviation: BeBq₂), bis(2-methyl-8-quinolinolato)(4-phenylphenolato)aluminum(III) (abbreviation: BAlq), bis(8-quinolinolato)zinc(II) (abbreviation: Znq), bis[2-(2-benzoxazolyl)phenolato]zinc(II) (abbreviation: ZnPBO), and bis[2-(2-benzothiazolyl)phenolato]zinc(II) (abbreviation: ZnBTZ); heterocyclic compounds such as 2-(4-biphenyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole (abbreviation: PBD), 1,3-bis[5-(p-tert-butylphenyl)-1,3,4-oxadiazol-2-yl]benzene (abbreviation: OXD-7), 3-(4-biphenyl)-4-phenyl-5-(4-tert-butylphenyl)-1,2,4-triazole (abbreviation: TAZ), 2,2',2''-(1,3,5-benzenetriyl)-tris(1-phenyl-1H-benzimidazole) (abbreviation: TPBI), bathophenanthroline (abbreviation: BPhen), bathocuproine (abbreviation: BCP), and 9-[4-(5-phenyl-1,3,4-oxadiazol-2-yl)phenyl]-9H-carbazole (abbreviation: CO11); and aromatic amine compounds such as 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (abbreviation: NPB or α-NPD), N,N'-bis(3-methylphenyl)-N,N'-diphenyl-[1,1'-biphenyl]-4,4'-diamine (abbreviation: TPD), and 4,4'-bis[N-(spiro-9,9'-bifluoren-2-yl)-N-phenylamino]biphenyl (abbreviation: BSPB). In addition, condensed polycyclic aromatic compounds such as anthracene derivatives, phenanthrene derivatives, pyrene derivatives, chrysene derivatives, and dibenzo[g,p]chrysene derivatives can be given, and specific examples are 9,10-diphenylanthracene (abbreviation: DPAnth), N,N-diphenyl-9-[4-(10-phenyl-9-anthryl)phenyl]-9H-carbazol-3-amine (abbreviation: CzA1PA), 4-(10-phenyl-9-anthryl)triphenylamine (abbreviation: DPhPA),

4-(9H-carbazol-9-yl)-4'-(10-phenyl-9-anthryl)triphenylamine (abbreviation: YGAPA), N,9-diphenyl-N-[4-(10-phenyl-9-anthryl)phenyl]-9H-carbazol-3-amine (abbreviation: PCAPA), N,9-diphenyl-N-{4-[4-(10-phenyl-9-anthryl)phenyl]phenyl}-9H-carbazol-3-amine (abbreviation: PCAPBA), N,9-diphenyl-N-(9,10-diphenyl-2-anthryl)-9H-carbazol-3-amine (abbreviation: 2PCAPA), 6,12-dimethoxy-5,11-diphenylchrysene, N,N,N',N'',N''',N''',N''''-octaphenyldibenzo[g,p]chrysene-2,7,10,15-tetramine (abbreviation: DBC1), 9-[4-(10-phenyl-9-anthryl)phenyl]-9H-carbazole (abbreviation: CzPA), 3,6-diphenyl-9-[4-(10-phenyl-9-anthryl)phenyl]-9H-carbazole (abbreviation: DPCzPA), 9,10-bis(3,5-diphenylphenyl)anthracene (abbreviation: DPPA), 9,10-di(2-naphthyl)anthracene (abbreviation: DNA), 2-tert-butyl-9,10-di(2-naphthyl)anthracene (abbreviation: t-BuDNA), 9,9'-bianthryl (abbreviation: BANT), 9,9'-(stilbene-3,3'-diyl)diphenanthrene (abbreviation: DPNS), 9,9'-(stilbene-4,4'-diyl)diphenanthrene (abbreviation: DPNS2), 3,3',3''-(benzene-1,3,5-triyl)tripylene (abbreviation: TPB3), and the like. One or more substances having a wider energy gap than the above-described guest material **122** is/are preferably selected from these and known substances.

The light-emitting layer **120** can have a structure in which two or more layers are stacked. For example, in the case where the light-emitting layer **120** is formed by stacking a first light-emitting layer and a second light-emitting layer in this order from the hole-transport layer side, the first light-emitting layer is formed using a substance having a hole-transport property as the host material and the second light-emitting layer is formed using a substance having an electron-transport property as the host material.

In the light-emitting layer **120**, the host material **121** may be composed of one kind of compound or a plurality of compounds. The light-emitting layer **120** may include a material other than the host material **121** and the guest material **122**.

<<Material that can be Used for Light-Emitting Layer **170**>>

As a material that can be used in the light-emitting layer **170**, a material that can be used for the light-emitting layer **140** in Embodiment 1 can be used. The use of the material which can be used for the light-emitting layer **140** as the material of the light-emitting layer **170** can make a light-emitting element with high emission efficiency.

There is no limitation on the emission colors of the light-emitting materials contained in the light-emitting layers **120** and **170**, and they may be the same or different. Light emitted from the light-emitting materials is mixed and extracted out of the element; therefore, for example, in the case where their emission colors are complementary colors, the light-emitting element can emit white light. In consideration of the reliability of the light-emitting element, the emission peak wavelength of the light-emitting material included in the light-emitting layer **120** is preferably shorter than that of the light-emitting material included in the light-emitting layer **170**.

Note that the light-emitting units **106** and **108** and the charge-generation layer **115** can be formed by an evaporation method (including a vacuum evaporation method), an ink-jet method, a coating method, gravure printing, or the like.

The structure described in this embodiment can be used in combination with any of the structures described in the other embodiments as appropriate.

EMBODIMENT 3

In this embodiment, examples of light-emitting elements having structures different from those described in Embodi-

ments 1 and 2 are described below with reference to FIGS. **5A** and **5B**, FIGS. **6A** and **6B**, FIGS. **7A** to **7C**, and FIGS. **8A** to **8C**.

STRUCTURE EXAMPLE 1 OF LIGHT-EMITTING ELEMENT

FIGS. **5A** and **5B** are cross-sectional views each illustrating a light-emitting element of one embodiment of the present invention. In FIGS. **5A** and **5B**, a portion having a function similar to that in FIG. **1A** is represented by the same hatch pattern as in FIG. **1A** and not especially denoted by a reference numeral in some cases. In addition, common reference numerals are used for portions having similar functions, and a detailed description of the portions is omitted in some cases.

Light-emitting elements **260a** and **260b** in FIGS. **5A** and **5B** may have a bottom-emission structure in which light is extracted through the substrate **200** or may have a top-emission structure in which light emitted from the light-emitting element is extracted in the direction opposite to the substrate **200**. However, one embodiment of the present invention is not limited to this structure, and a light-emitting element having a dual-emission structure in which light emitted from the light-emitting element is extracted in both top and bottom directions of the substrate **200** may be used.

In the case where the light-emitting elements **260a** and **260b** each have a bottom emission structure, the electrode **101** preferably has a function of transmitting light and the electrode **102** preferably has a function of reflecting light. Alternatively, in the case where the light-emitting elements **260a** and **260b** each have a top emission structure, the electrode **101** preferably has a function of reflecting light and the electrode **102** preferably has a function of transmitting light.

The light-emitting elements **260a** and **260b** each include the electrode **101** and the electrode **102** over the substrate **200**. Between the electrodes **101** and **102**, a light-emitting layer **123B**, a light-emitting layer **123G**, and a light-emitting layer **123R** are provided. The hole-injection layer **111**, the hole-transport layer **112**, the electron-transport layer **118**, and the electron-injection layer **119** are also provided.

The light-emitting element **260b** includes, as part of the electrode **101**, a conductive layer **101a**, a conductive layer **101b** over the conductive layer **101a**, and a conductive layer **101c** under the conductive layer **101a**. In other words, the light-emitting element **260b** includes the electrode **101** having a structure in which the conductive layer **101a** is sandwiched between the conductive layer **101b** and the conductive layer **101c**.

In the light-emitting element **260b**, the conductive layer **101b** and the conductive layer **101c** may be formed of different materials or the same material. The electrode **101** preferably has a structure in which the conductive layer **101** is sandwiched by the layers formed of the same conductive material, in which case patterning by etching in the process for forming the electrode **101** can be performed easily.

Note that the light-emitting element **260b** may include either the conductive layer **101b** or the conductive layer **101c**.

For each of the conductive layers **101a**, **101b**, and **101c**, which are included in the electrode **101**, the structure and materials of the electrode **101** or **102** described in Embodiment 1 can be used.

In FIGS. **5A** and **5B**, a partition wall **145** is provided between a region **221B**, a region **221G**, and a region **221R**, which are sandwiched between the electrode **101** and the

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electrode **102**. The partition wall **145** has an insulating property. The partition wall **145** covers end portions of the electrode **101** and has openings overlapping with the electrode. With the partition wall **145**, the electrode **101** provided over the substrate **200** in the regions can be divided into island shapes.

Note that the light-emitting layer **123B** and the light-emitting layer **123G** may overlap with each other in a region where they overlap with the partition wall **145**. The light-emitting layer **123G** and the light-emitting layer **123R** may overlap with each other in a region where they overlap with the partition wall **145**. The light-emitting layer **123R** and the light-emitting layer **123B** may overlap with each other in a region where they overlap with the partition wall **145**.

The partition wall **145** has an insulating property and is formed using an inorganic or organic material. Examples of the inorganic material include silicon oxide, silicon oxynitride, silicon nitride oxide, silicon nitride, aluminum oxide, and aluminum nitride. Examples of the organic material include photosensitive resin materials such as an acrylic resin and a polyimide resin.

Note that a silicon oxynitride film refers to a film in which the proportion of oxygen is higher than that of nitrogen. The silicon oxynitride film preferably contains oxygen, nitrogen, silicon, and hydrogen in the ranges of 55 atomic % to 65 atomic %, 1 atomic % to 20 atomic %, 25 atomic % to 35 atomic %, and 0.1 atomic % to 10 atomic %, respectively. A silicon nitride oxide film refers to a film in which the proportion of nitrogen is higher than that of oxygen. The silicon nitride oxide film preferably contains nitrogen, oxygen, silicon, and hydrogen in the ranges of 55 atomic % to 65 atomic %, 1 atomic % to 20 atomic %, 25 atomic % to 35 atomic %, and 0.1 atomic % to 10 atomic %, respectively.

The light-emitting layers **123R**, **123G**, and **123B** preferably contain light-emitting materials having functions of emitting light of different colors. For example, when the light-emitting layer **123R** contains a light-emitting material having a function of emitting red, the region **221R** emits red light. When the light-emitting layer **123G** contains a light-emitting material having a function of emitting green, the region **221G** emits green light. When the light-emitting layer **123B** contains a light-emitting material having a function of emitting blue, the region **221B** emits blue light. The light-emitting element **260a** or **260b** having such a structure is used in a pixel of a display device, whereby a full-color display device can be fabricated. The thicknesses of the light-emitting layers may be the same or different.

One or more of the light-emitting layer **123B**, the light-emitting layer **123G**, and the light-emitting layer **123R** preferably have a structure similar to the structure of the light-emitting layer **140** described in Embodiment 1. In that case, a light-emitting element with high emission efficiency can be fabricated.

One or more of the light-emitting layers **123B**, **123G**, and **123R** may include two or more stacked layers.

When at least one light-emitting layer includes the light-emitting layer described in Embodiments 1 and 2 as described above and the light-emitting element **260a** or **260b** including the light-emitting layer is used in pixels in a display device, a display device with high emission efficiency can be fabricated. The display device including the light-emitting element **260a** or **260b** can thus have reduced power consumption.

By providing an optical element (e.g., a color filter, a polarizing plate, and an anti-reflection film) on the light extraction side of the electrode through which light is extracted, the color purity of each of the light-emitting

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elements **260a** and **260b** can be improved. Therefore, the color purity of a display device including the light-emitting element **260a** or **260b** can be improved. Alternatively, the reflection of external light by each of the light-emitting elements **260a** and **260b** can be reduced. Therefore, the contrast ratio of a display device including the light-emitting element **260a** or **260b** can be improved.

For the other components of the light-emitting elements **260a** and **260b**, the components of the light-emitting element in Embodiments 1 and 2 may be referred to.

STRUCTURE EXAMPLE 2 OF LIGHT-EMITTING ELEMENT

Next, structure examples different from the light-emitting elements illustrated in FIGS. **5A** and **5B** will be described below with reference to FIGS. **6A** and **6B**.

FIGS. **6A** and **6B** are cross-sectional views of a light-emitting element of one embodiment of the present invention. In FIGS. **6A** and **6B**, a portion having a function similar to that in FIGS. **5A** and **5B** is represented by the same hatch pattern as in FIGS. **5A** and **5B** and not especially denoted by a reference numeral in some cases. In addition, common reference numerals are used for portions having similar functions, and a detailed description of such portions is not repeated in some cases.

FIGS. **6A** and **6B** illustrate structure examples of a light-emitting element including the light-emitting layer between a pair of electrodes. A light-emitting element **262a** illustrated in FIG. **6A** has a top-emission structure in which light is extracted in a direction opposite to the substrate **200**, and a light-emitting element **262b** illustrated in FIG. **6B** has a bottom-emission structure in which light is extracted to the substrate **200** side. However, one embodiment of the present invention is not limited to these structures and may have a dual-emission structure in which light emitted from the light-emitting element is extracted in both top and bottom directions with respect to the substrate **200** over which the light-emitting element is formed.

The light-emitting elements **262a** and **262b** each include the electrode **101**, the electrode **102**, an electrode **103**, and an electrode **104** over the substrate **200**. At least a light-emitting layer **170**, a light-emitting layer **190**, and the charge-generation layer **115** are provided between the electrode **101** and the electrode **102**, between the electrode **102** and the electrode **103**, and between the electrode **102** and the electrode **104**. The hole-injection layer **111**, the hole-transport layer **112**, the electron-transport layer **113**, the electron-injection layer **114**, the hole-injection layer **116**, the hole-transport layer **117**, the electron-transport layer **118**, and the electron-injection layer **119** are further provided.

The electrode **101** includes a conductive layer **101a** and a conductive layer **101b** over and in contact with the conductive layer **101a**. The electrode **103** includes a conductive layer **103a** and a conductive layer **103b** over and in contact with the conductive layer **103a**. The electrode **104** includes a conductive layer **104a** and a conductive layer **104b** over and in contact with the conductive layer **104a**.

The light-emitting element **262a** illustrated in FIG. **6A** and the light-emitting element **262b** illustrated in FIG. **6B** each include a partition wall **145** between a region **222B** sandwiched between the electrode **101** and the electrode **102**, a region **222G** sandwiched between the electrode **102** and the electrode **103**, and a region **222R** sandwiched between the electrode **102** and the electrode **104**. The partition wall **145** has an insulating property. The partition wall **145** covers end portions of the electrodes **101**, **103**, and

104 and has openings overlapping with the electrodes. With the partition wall **145**, the electrodes provided over the substrate **200** in the regions can be separated into island shapes.

The charge-generation layer **115** can be foliated with a material obtained by adding an electron acceptor (acceptor) to a hole-transport material or a material obtained by adding an electron donor (donor) to an electron-transport material. Note that when the conductivity of the charge-generation layer **115** is as high as that of the pair of electrodes, carriers generated in the charge-generation layer **115** might transfer to an adjacent pixel and light emission might occur in the pixel. In order to prevent such false light emission from an adjacent pixel, the charge-generation layer **115** is preferably formed with a material whose conductivity is lower than that of the pair of electrodes.

The light-emitting elements **262a** and **262b** each include a substrate **220** provided with an optical element **224B**, an optical element **224G**, and an optical element **224R** in the direction in which light emitted from the region **222B**, light emitted from the region **222G**, and light emitted from the region **222R** are extracted. The light emitted from each region is emitted outside the light-emitting element through each optical element. In other words, the light from the region **222B**, the light from the region **222G**, and the light from the region **222R** are emitted through the optical element **224B**, the optical element **224G**, and the optical element **224R**, respectively.

The optical elements **224B**, **224G**, and **224R** each have a function of selectively transmitting light of a particular color out of incident light. For example, the light emitted from the region **222B** through the optical element **224B** is blue light, the light emitted from the region **222G** through the optical element **224G** is green light, and the light emitted from the region **222R** through the optical element **224R** is red light.

For example, a coloring layer (also referred to as color filter), a band pass filter, a multilayer filter, or the like can be used for the optical elements **224R**, **224G**, and **224B**. Alternatively, color conversion elements can be used as the optical elements. A color conversion element is an optical element that converts incident light into light having a longer wavelength than the incident light. As the color conversion elements, quantum-dot elements can be favorably used. The usage of the quantum-dot type can increase color reproducibility of the display device.

One or more optical elements may be stacked over each of the optical elements **224R**, **224G**, and **224B**. As another optical element, a circularly polarizing plate, an anti-reflective film, or the like can be provided, for example. A circularly polarizing plate provided on the side where light emitted from the light-emitting element of the display device is extracted can prevent a phenomenon in which light entering from the outside of the display device is reflected inside the display device and returned to the outside. An anti-reflective film can weaken external light reflected by a surface of the display device. This leads to clear observation of light emitted from the display device.

Note that in FIGS. **6A** and **6B**, blue light (B), green light (G), and red light (R) emitted from the regions through the optical elements are schematically illustrated by arrows of dashed lines.

A light-blocking layer **223** is provided between the optical elements. The light-blocking layer **223** has a function of blocking light emitted from the adjacent regions. Note that a structure without the light-blocking layer **223** may also be employed.

The light-blocking layer **223** has a function of reducing the reflection of external light. The light-blocking layer **223** has a function of preventing mixture of light emitted from an adjacent light-emitting element. As the light-blocking layer **223**, a metal, a resin containing black pigment, carbon black, a metal oxide, a composite oxide containing a solid solution of a plurality of metal oxides, or the like can be used.

Note that the optical element **224B** and the optical element **224G** may overlap with each other in a region where they overlap with the light-blocking layer **223**. In addition, the optical element **224G** and the optical element **224R** may overlap with each other in a region where they overlap with the light-blocking layer **223**. In addition, the optical element **224R** and the optical element **224B** may overlap with each other in a region where they overlap with the light-blocking layer **223**.

As for the structures of the substrate **200** and the substrate **220** provided with the optical elements, Embodiment 1 can be referred to.

Furthermore, the light-emitting elements **262a** and **262b** have a microcavity structure.

<<Microcavity Structure>>

Light emitted from the light-emitting layer **170** and the light-emitting layer **190** resonates between a pair of electrodes (e.g., the electrode **101** and the electrode **102**). The light-emitting layer **170** and the light-emitting layer **190** are formed at such a position as to intensify the light of a desired wavelength among light to be emitted. For example, by adjusting the optical length from a reflective region of the electrode **101** to the light-emitting region of the light-emitting layer **170** and the optical length from a reflective region of the electrode **102** to the light-emitting region of the light-emitting layer **170**, the light of a desired wavelength among light emitted from the light-emitting layer **170** can be intensified. By adjusting the optical length from the reflective region of the electrode **101** to the light-emitting region of the light-emitting layer **190** and the optical length from the reflective region of the electrode **102** to the light-emitting region of the light-emitting layer **190**, the light of a desired wavelength among light emitted from the light-emitting layer **190** can be intensified. In the case of a light-emitting element in which a plurality of light-emitting layers (here, the light-emitting layers **170** and **190**) are stacked, the optical lengths of the light-emitting layers **170** and **190** are preferably optimized.

In each of the light-emitting elements **262a** and **262b**, by adjusting the thicknesses of the conductive layers (the conductive layer **101b**, the conductive layer **103b**, and the conductive layer **104b**) in each region, the light of a desired wavelength among light emitted from the light-emitting layers **170** and **190** can be increased. Note that the thickness of at least one of the hole-injection layer **111** and the hole-transport layer **112** may differ between the regions to increase the light emitted from the light-emitting layers **170** and **190**.

For example, in the case where the refractive index of the conductive material having a function of reflecting light in the electrodes **101** to **104** is lower than the refractive index of the light-emitting layer **170** or **190**, the thickness of the conductive layer **101b** of the electrode **101** is adjusted so that the optical length between the electrode **101** and the electrode **102** is $m_B \lambda_B / 2$ (m_B is a natural number and λ_B is the wavelength of light intensified in the region **222B**). Similarly, the thickness of the conductive layer **103b** of the electrode **103** is adjusted so that the optical length between the electrode **103** and the electrode **102** is $m_G \lambda_G / 2$ (m_G is a natural number and λ_G is the wavelength of light intensified

in the region 222G). Furthermore, the thickness of the conductive layer 104b of the electrode 104 is adjusted so that the optical length between the electrode 104 and the electrode 102 is $m_R \lambda_R / 2$ (m_R is a natural number and λ_R is the wavelength of light intensified in the region 222R).

In the case where it is difficult to precisely determine the reflective regions of the electrodes 101 to 104, the optical length for increasing the intensity of light emitted from the light-emitting layer 170 or the light-emitting layer 190 may be derived on the assumption that certain regions of the electrodes 101 to 104 are the reflective regions. In the case where it is difficult to precisely determine the light-emitting regions of the light-emitting layer 170 and the light-emitting layer 190, the optical length for increasing the intensity of light emitted from the light-emitting layer 170 and the light-emitting layer 190 may be derived on the assumption that certain regions of the light-emitting layer 170 and the light-emitting layer 190 are the light-emitting regions.

In the above manner, with the microcavity structure, in which the optical length between the pair of electrodes in the respective regions is adjusted, scattering and absorption of light in the vicinity of the electrodes can be suppressed, resulting in high light extraction efficiency.

In the above structure, the conductive layers 101b, 103b, and 104b preferably have a function of transmitting light. The materials of the conductive layers 101b, 103b, and 104b may be the same or different. It is preferable to use the same material for the conductive layer 101b, the conductive layer 103b, and the conductive layer 104b because patterning by etching in the formation process of the electrode 101, the electrode 103, and the electrode 104 can be performed easily. Each of the conductive layers 101b, 103b, and 104b may have a stacked structure of two or more layers.

Since the light-emitting element 262a illustrated in FIG. 6A has a top-emission structure, it is preferable that the conductive layer 101a, the conductive layer 103a, and the conductive layer 104a have a function of reflecting light. In addition, it is preferable that the electrode 102 have functions of transmitting light and reflecting light.

Since the light-emitting element 262b illustrated in FIG. 6B has a bottom-emission structure, it is preferable that the conductive layer 101a, the conductive layer 103a, and the conductive layer 104a have functions of transmitting light and reflecting light. In addition, it is preferable that the electrode 102 have a function of reflecting light.

In each of the light-emitting elements 262a and 262b, the conductive layers 101a, 103a, and 104a may be formed of different materials or the same material. When the conductive layers 101a, 103a, and 104a are formed of the same material, manufacturing cost of the light-emitting elements 262a and 262b can be reduced. Note that each of the conductive layers 101a, 103a, and 104a may have a stacked structure including two or more layers.

At least one of the structures described in Embodiments 1 and 2 is preferably used for at least one of the light-emitting layers 170 and 190 included in the light-emitting elements 262a and 262b. In this way, the light-emitting elements can have high emission efficiency.

Either or both of the light-emitting layers 170 and 190 may have a stacked structure of two layers like the light-emitting layers 190a and 190b, for example. The two light-emitting layers each including two kinds of light-emitting materials (a first compound and a second compound) for emitting light of different colors enable emission of light of a plurality of colors. It is particularly preferable to select the light-emitting materials of the light-emitting

layers so that white light can be obtained by combining light emissions from the light-emitting layers 170 and 190.

Either or both of the light-emitting layers 170 and 190 may have a stacked structure of three or more layers, in which a layer not including a light-emitting material may be included.

In the above-described manner, by using the light-emitting element 262a or 262b including the light-emitting layer having at least one of the structures described in Embodiments 1 and 2 in pixels in a display device, a display device with high emission efficiency can be fabricated. Accordingly, the display device including the light-emitting element 262a or 262b can have low power consumption.

For the other components of the light-emitting elements 262a and 262b, the components of the light-emitting element 260a or 260b or the light-emitting element in Embodiment 1 and 2 may be referred to.

<Fabrication Method of Light-Emitting Element>

Next, a method for fabricating a light-emitting element of one embodiment of the present invention is described below with reference to FIGS. 7A to 7C and FIGS. 8A to 8C. Here, a method for fabricating the light-emitting element 262a illustrated in FIG. 6A is described.

FIGS. 7A to 7C and FIGS. 8A to 8C are cross-sectional views illustrating a method for fabricating the light-emitting element of one embodiment of the present invention.

The method for fabricating the light-emitting element 262a described below includes first to seventh steps.

<<First Step>>

In the first step, the electrodes (specifically the conductive layer 101a of the electrode 101, the conductive layer 103a of the electrode 103, and the conductive layer 104a of the electrode 104) of the light-emitting elements are formed over the substrate 200 (see FIG. 7A).

In this embodiment, a conductive layer having a function of reflecting light is formed over the substrate 200 and processed into a desired shape; whereby the conductive layers 101a, 103a, and 104a are formed. As the conductive layer having a function of reflecting light, an alloy film of silver, palladium, and copper (also referred to as an Ag—Pd—Cu film or APC) is used. The conductive layers 101a, 103a, and 104a are preferably formed through a step of processing the same conductive layer, because the manufacturing cost can be reduced.

Note that a plurality of transistors may be formed over the substrate 200 before the first step. The plurality of transistors may be electrically connected to the conductive layers 101a, 103a, and 104a.

<<Second Step>>

In the second step, the transparent conductive layer 101b having a function of transmitting light is formed over the conductive layer 101a of the electrode 101, the transparent conductive layer 103b having a function of transmitting light is formed over the conductive layer 103a of the electrode 103, and the transparent conductive layer 104b having a function of transmitting light is formed over the conductive layer 104a of the electrode 104 (see FIG. 7B).

In this embodiment, the conductive layers 101b, 103b, and 104b each having a function of transmitting light are formed over the conductive layers 101a, 103a, and 104a each having a function of reflecting light, respectively, whereby the electrode 101, the electrode 103, and the electrode 104 are formed. As the conductive layers 101b, 103b, and 104b, ITO films are used.

The conductive layers 101b, 103b, and 104b having a function of transmitting light may be formed in a plurality of steps. When the conductive layers 101b, 103b, and 104b

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having a function of transmitting light are formed in a plurality of steps, they can be formed to have thicknesses which enable microcavity structures appropriate in the respective regions.

<<Third Step>>

In the third step, the partition wall **145** that covers end portions of the electrodes of the light-emitting element is formed (see FIG. 7C).

The partition wall **145** includes an opening overlapping with the electrode. The conductive film exposed by the opening functions as the anode of the light-emitting element. As the partition wall **145**, a polyimide-based resin is used in this embodiment.

In the first to third steps, since there is no possibility of damaging the EL layer (a layer containing an organic compound), a variety of film formation methods and micro-machining technologies can be employed. In this embodiment, a reflective conductive layer is formed by a sputtering method, a pattern is formed over the conductive layer by a lithography method, and then the conductive layer is processed into an island shape by a dry etching method or a wet etching method to form the conductive layer **101a** of the electrode **101**, the conductive layer **103a** of the electrode **103**, and the conductive layer **104a** of the electrode **104**. Then, a transparent conductive film is formed by a sputtering method, a pattern is formed over the transparent conductive film by a lithography method, and then the transparent conductive film is processed into island shapes by a wet etching method to form the electrodes **101**, **103**, and **104**.

<<Fourth Step>>

In the fourth step, the hole-injection layer **111**, the hole-transport layer **112**, the light-emitting layer **190**, the electron-transport layer **113**, the electron-injection layer **114**, and the charge-generation layer **115** are formed (see FIG. 8A).

The hole-injection layer **111** can be formed by co-evaporating a hole-transport material and a material containing an acceptor substance. Note that a co-evaporation method is an evaporation method in which a plurality of different substances are concurrently vaporized from respective different evaporation sources. The hole-transport layer **112** can be formed by evaporating a hole-transport material.

The light-emitting layer **190** can be formed by evaporating a guest material that emits light of at least one color selected from violet, blue, blue green, green, yellow green, yellow, orange, and red. As the guest material, a fluorescent or phosphorescent organic material can be used. The structure of the light-emitting layer described in Embodiment 1 or Embodiment 2 is preferably employed. The light-emitting layer **190** may have a two-layer structure. In such a case, the two light-emitting layers each preferably contain a light-emitting material that emits light of a different color.

The electron-transport layer **113** can be formed by evaporating a substance having a high electron-transport property. The electron-injection layer **114** can be formed by evaporating a substance having a high electron-injection property.

The charge-generation layer **115** can be formed by evaporating a material obtained by adding an electron acceptor (acceptor) to a hole-transport material or a material obtained by adding an electron donor (donor) to an electron-transport material.

<<Fifth Step>>

In the fifth step, the hole-injection layer **116**, the hole-transport layer **117**, the light-emitting layer **170**, the electron-transport layer **118**, the electron-injection layer **119**, and the electrode **102** are formed (see FIG. 8B).

The hole-injection layer **116** can be formed by using a material and a method which are similar to those of the

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hole-injection layer **111**. The hole-transport layer **117** can be formed by using a material and a method which are similar to those of the hole-transport layer **112**.

The light-emitting layer **170** can be formed by evaporating a guest material that emits light of at least one color selected from violet, blue, blue green, green, yellow green, yellow, orange, and red. As the guest material, a fluorescent or phosphorescent organic compound can be used. The structure of the light-emitting layer described in Embodiment 1 is preferably employed. Note that at least one of the light-emitting layer **170** and the light-emitting layer **190** preferably has the structure of a light-emitting layer described in Embodiment 1 or Embodiment 2. The light-emitting layer **170** and the light-emitting layer **190** preferably include light-emitting organic compounds exhibiting light of different colors.

The electron-transport layer **118** can be formed by using a material and a method which are similar to those of the electron-transport layer **113**. The electron-injection layer **119** can be formed by using a material and a method which are similar to those of the electron-injection layer **114**.

The electrode **102** can be formed by stacking a reflective conductive film and a light-transmitting conductive film. The electrode **102** may have a single-layer structure or a stacked-layer structure.

Through the above-described steps, the light-emitting element including the region **222B**, the region **222G**, and the region **222R** over the electrode **101**, the electrode **103**, and the electrode **104**, respectively, are formed over the substrate **200**.

<<Sixth Step>>

In the sixth step, the light-blocking layer **223**, the optical element **224B**, the optical element **224G**, and the optical element **224R** are formed over the substrate **220** (see FIG. 8C).

As the light-blocking layer **223**, a resin film containing black pigment is formed in a desired region. Then, the optical element **224B**, the optical element **224G**, and the optical element **224R** are formed over the substrate **220** and the light-blocking layer **223**. As the optical element **224B**, a resin film containing blue pigment is formed in a desired region. As the optical element **224G**, a resin film containing green pigment is formed in a desired region. As the optical element **224R**, a resin film containing red pigment is formed in a desired region.

<<Seventh Step>>

In the seventh step, the light-emitting element formed over the substrate **200** is attached to the light-blocking layer **223**, the optical element **224B**, the optical element **224G**, and the optical element **224R** formed over the substrate **220**, and sealed with a sealant (not illustrated).

Through the above-described steps, the light-emitting element **262a** illustrated in FIG. 6A can be formed.

The structure described in this embodiment can be used in combination with any of the structures described in the other embodiments as appropriate.

EMBODIMENT 4

In this embodiment, a display device of one embodiment of the present invention will be described below with reference to FIGS. 9A and 9B, FIGS. 10A and 10B, FIG. 11, FIGS. 12A and 12B, FIGS. 13A and 13B, FIG. 14, FIGS. 15A and 15B, FIG. 16, and FIGS. 17A and 17B.

STRUCTURE EXAMPLE 1 OF DISPLAY DEVICE

FIG. 9A is a top view illustrating a display device **600** and FIG. 9B is a cross-sectional view taken along the dashed-

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dotted line A-B and the dashed-dotted line C-D in FIG. 9A. The display device 600 includes driver circuit portions (a signal line driver circuit portion 601 and a scan line driver circuit portion 603) and a pixel portion 602. Note that the signal line driver circuit portion 601, the scan line driver circuit portion 603, and the pixel portion 602 have a function of controlling light emission from a light-emitting element.

The display device 600 also includes an element substrate 610, a sealing substrate 604, a sealant 605, a region 607 surrounded by the sealant 605, a lead wiring 608, and an FPC 609.

Note that the lead wiring 608 is a wiring for transmitting signals to be input to the signal line driver circuit portion 601 and the scan line driver circuit portion 603 and for receiving a video signal, a clock signal, a start signal, a reset signal, and the like from the FPC 609 serving as an external input terminal. Although only the FPC 609 is illustrated here, the FPC 609 may be provided with a printed wiring board (PWB).

As the signal line driver circuit portion 601, a CMOS circuit in which an n-channel transistor 623 and a p-channel transistor 624 are combined is formed. As the signal line driver circuit portion 601 or the scan line driver circuit portion 603, various types of circuits such as a CMOS circuit, a PMOS circuit, or an NMOS circuit can be used. Although a driver in which a driver circuit portion is formed and a pixel are formed over the same surface of a substrate in the display device of this embodiment, the driver circuit portion is not necessarily formed over the substrate and can be formed outside the substrate.

The pixel portion 602 includes a switching transistor 611, a current control transistor 612, and a lower electrode 613 electrically connected to a drain of the current control transistor 612. Note that a partition wall 614 is formed to cover end portions of the lower electrode 613. As the partition wall 614, for example, a positive type photosensitive acrylic resin film can be used.

In order to obtain favorable coverage, the partition wall 614 is formed to have a curved surface with curvature at its upper or lower end portion. For example, in the case of using a positive photosensitive acrylic as a material of the partition wall 614, it is preferable that only the upper end portion of the partition wall 614 have a curved surface with curvature (the radius of the curvature being 0.2 μm to 3 μm). As the partition wall 614, either a negative photosensitive resin or a positive photosensitive resin can be used.

Note that there is no particular limitation on a structure of each of the transistors (the transistors 611, 612, 623, and 624). For example, a staggered transistor can be used. In addition, there is no particular limitation on the polarity of these transistors. For these transistors, n-channel and p-channel transistors may be used, or either n-channel transistors or p-channel transistors may be used, for example. Furthermore, there is no particular limitation on the crystallinity of a semiconductor film used for these transistors. For example, an amorphous semiconductor film or a crystalline semiconductor film may be used. Examples of a semiconductor material include Group 14 semiconductors (e.g., a semiconductor including silicon), compound semiconductors (including oxide semiconductors), organic semiconductors, and the like. For example, it is preferable to use an oxide semiconductor that has an energy gap of 2 eV or more, preferably 2.5 eV or more and further preferably 3 eV or more, for the transistors, so that the off-state current of the transistors can be reduced. Examples of the oxide semiconductor include an In—Ga oxide and an In—M—Zn oxide (M is aluminum (Al), gallium (Ga), yttrium (Y),

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zirconium (Zr), lanthanum (La), cerium (Ce), tin (Sn), hafnium (Hf), or neodymium (Nd)).

An EL layer 616 and an upper electrode 617 are formed over the lower electrode 613. Here, the lower electrode 613 functions as an anode and the upper electrode 617 functions as a cathode.

In addition, the EL layer 616 is formed by various methods such as an evaporation method with an evaporation mask, an ink-jet method, or a spin coating method. As another material included in the EL layer 616, a low molecular compound or a high molecular compound (including an oligomer or a dendrimer) may be used.

Note that a light-emitting element 618 is formed with the lower electrode 613, the EL layer 616, and the upper electrode 617. The light-emitting element 618 preferably has any of the structures described in Embodiments 1 to 3. In the case where the pixel portion includes a plurality of light-emitting elements, the pixel portion may include both any of the light-emitting elements described in Embodiments 1 to 3 and a light-emitting element having a different structure.

When the sealing substrate 604 and the element substrate 610 are attached to each other with the sealant 605, the light-emitting element 618 is provided in the region 607 surrounded by the element substrate 610, the sealing substrate 604, and the sealant 605. The region 607 is filled with a filler. In some cases, the region 607 is filled with an inert gas (nitrogen, argon, or the like) or filled with an ultraviolet curable resin or a thermosetting resin which can be used for the sealant 605. For example, a polyvinyl chloride (PVC)-based resin, an acrylic-based resin, a polyimide-based resin, an epoxy-based resin, a silicone-based resin, a polyvinyl butyral (PVB)-based resin, or an ethylene vinyl acetate (EVA)-based resin can be used. It is preferable that the sealing substrate be provided with a recessed portion and a desiccant be provided in the recessed portion, in which case deterioration due to influence of moisture can be inhibited.

An optical element 621 is provided below the sealing substrate 604 to overlap with the light-emitting element 618. A light-blocking layer 622 is provided below the sealing substrate 604. The structures of the optical element 621 and the light-blocking layer 622 can be the same as those of the optical element and the light-blocking layer in Embodiment 3, respectively.

An epoxy-based resin or glass frit is preferably used for the sealant 605. It is preferable that such a material do not transmit moisture or oxygen as much as possible. As the sealing substrate 604, a glass substrate, a quartz substrate, or a plastic substrate formed of fiber reinforced plastic (FRP), poly(vinyl fluoride) (PVF), polyester, acrylic, or the like can be used.

In the above-described manner, the display device including any of the light-emitting elements and the optical elements which are described in Embodiments 1 to 3 can be obtained.

STRUCTURE EXAMPLE 2 OF DISPLAY DEVICE

Next, another example of the display device is described with reference to FIGS. 10A and 10B and FIG. 11. Note that FIGS. 10A and 10B and FIG. 11 are each a cross-sectional view of a display device of one embodiment of the present invention.

In FIG. 10A, a substrate 1001, a base insulating film 1002, a gate insulating film 1003, gate electrodes 1006, 1007, and 1008, a first interlayer insulating film 1020, a second interlayer insulating film 1021, a peripheral portion 1042, a pixel

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portion **1040**, a driver circuit portion **1041**, lower electrodes **1024R**, **1024G**, and **1024B** of light-emitting elements, a partition wall **1025**, an EL layer **1028**, an upper electrode **1026** of the light-emitting elements, a sealing layer **1029**, a sealing substrate **1031**, a sealant **1032**, and the like are illustrated.

In FIG. **10A**, examples of the optical elements, coloring layers (a red coloring layer **1034R**, a green coloring layer **1034G**, and a blue coloring layer **1034B**) are provided on a transparent base material **1033**. Further, a light-blocking layer **1035** may be provided. The transparent base material **1033** provided with the coloring layers and the light-blocking layer is positioned and fixed to the substrate **1001**. Note that the coloring layers and the light-blocking layer are covered with an overcoat layer **1036**. In the structure in FIG. **10A**, red light, green light, and blue light transmit the coloring layers, and thus an image can be displayed with the use of pixels of three colors.

FIG. **10B** illustrates an example in which, as examples of the optical elements, the coloring layers (the red coloring layer **1034R**, the green coloring layer **1034G**, and the blue coloring layer **1034B**) are provided between the gate insulating film **1003** and the first interlayer insulating film **1020**. As in this structure, the coloring layers may be provided between the substrate **1001** and the sealing substrate **1031**.

FIG. **11** illustrates an example in which, as examples of the optical elements, the coloring layers (the red coloring layer **1034R**, the green coloring layer **1034G**, and the blue coloring layer **1034B**) are provided between the first interlayer insulating film **1020** and the second interlayer insulating film **1021**. As in this structure, the coloring layers may be provided between the substrate **1001** and the sealing substrate **1031**.

The above-described display device has a structure in which light is extracted from the substrate **1001** side where the transistors are formed (a bottom-emission structure), but may have a structure in which light is extracted from the sealing substrate **1031** side (a top-emission structure).

STRUCTURE EXAMPLE 3 OF DISPLAY DEVICE

FIGS. **12A** and **12B** are each an example of a cross-sectional view of a display device having a top emission structure. Note that FIGS. **12A** and **12B** are each a cross-sectional view illustrating the display device of one embodiment of the present invention, and the driver circuit portion **1041**, the peripheral portion **1042**, and the like, which are illustrated in FIGS. **10A** and **10B** and FIG. **11**, are not illustrated therein.

In this case, as the substrate **1001**, a substrate that does not transmit light can be used. The process up to the step of forming a connection electrode which connects the transistor and the anode of the light-emitting element is performed in a manner similar to that of the display device having a bottom-emission structure. Then, a third interlayer insulating film **1037** is formed to cover an electrode **1022**. This insulating film may have a planarization function. The third interlayer insulating film **1037** can be formed using a material similar to that of the second interlayer insulating film, or can be formed using any other various materials.

The lower electrodes **1024R**, **1024G**, and **1024B** of the light-emitting elements each function as an anode here, but may function as a cathode. Further, in the case of a display device having a top-emission structure as illustrated in FIGS. **12A** and **12B**, the lower electrodes **1024R**, **1024G**, and **1024B** preferably have a function of reflecting light. The

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upper electrode **1026** is provided over the EL layer **1028**. It is preferable that the upper electrode **1026** have a function of reflecting light and a function of transmitting light and that a microcavity structure be used between the upper electrode **1026** and the lower electrodes **1024R**, **1024G**, and **1024B**, in which case the intensity of light having a specific wavelength is increased.

In the case of a top-emission structure as illustrated in FIG. **12A**, sealing can be performed with the sealing substrate **1031** on which the coloring layers (the red coloring layer **1034R**, the green coloring layer **1034G**, and the blue coloring layer **1034B**) are provided. The sealing substrate **1031** may be provided with the light-blocking layer **1035** which is positioned between pixels. Note that a light-transmitting substrate is favorably used as the sealing substrate **1031**.

FIG. **12A** illustrates the structure provided with the light-emitting elements and the coloring layers for the light-emitting elements as an example; however, the structure is not limited thereto. For example, as shown in FIG. **12B**, a structure including the red coloring layer **1034R** and the blue coloring layer **1034B** but not including a green coloring layer may be employed to achieve full color display with the three colors of red, green, and blue. The structure as illustrated in FIG. **12A** where the light-emitting elements are provided with the coloring layers is effective to suppress reflection of external light. In contrast, the structure as illustrated in FIG. **12B** where the light-emitting elements are provided with the red coloring layer and the blue coloring layer and without the green coloring layer is effective to reduce power consumption because of small energy loss of light emitted from the green light-emitting element.

STRUCTURE EXAMPLE 4 OF DISPLAY DEVICE

Although a display device including sub-pixels of three colors (red, green, and blue) is described above, the number of colors of sub-pixels may be four (red, green, blue, and yellow, or red, green, blue, and white). FIGS. **13A** and **13B**, FIG. **14**, and FIGS. **15A** and **15B** illustrate structures of display devices each including the lower electrodes **1024R**, **1024G**, **1024B**, and **1024Y**. FIGS. **13A** and **13B** and FIG. **14** each illustrate a display device having a structure in which light is extracted from the substrate **1001** side on which transistors are formed (bottom-emission structure), and FIGS. **15A** and **15B** each illustrate a display device having a structure in which light is extracted from the sealing substrate **1031** side (top-emission structure).

FIG. **13A** illustrates an example of a display device in which optical elements (the coloring layer **1034R**, the coloring layer **1034G**, the coloring layer **1034B**, and a coloring layer **1034Y**) are provided on the transparent base material **1033**. FIG. **13B** illustrates an example of a display device in which optical elements (the coloring layer **1034R**, the coloring layer **1034G**, and the coloring layer **1034B**) are provided between the gate insulating film **1003** and the first interlayer insulating film **1020**. FIG. **14** illustrates an example of a display device in which optical elements (the coloring layer **1034R**, the coloring layer **1034G**, the coloring layer **1034B**, and the coloring layer **1034Y**) are provided between the first interlayer insulating film **1020** and the second interlayer insulating film **1021**.

The coloring layer **1034R** transmits red light, the coloring layer **1034G** transmits green light, and the coloring layer **1034B** transmits blue light. The coloring layer **1034Y** transmits yellow light or transmits light of a plurality of colors

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selected from blue, green, yellow, and red. When the coloring layer **1034Y** can transmit light of a plurality of colors selected from blue, green, yellow, and red, light released from the coloring layer **1034Y** may be white light. Since the light-emitting element which transmits yellow or white light has high emission efficiency, the display device including the coloring layer **1034Y** can have lower power consumption.

In the top-emission display devices illustrated in FIGS. **15A** and **15B**, a light-emitting element including the lower electrode **1024Y** preferably has a microcavity structure between the lower electrode and the upper electrode **1026** and the lower electrodes **1024R**, **1024G**, **1024B**, and **1024Y** as in the display device illustrated in FIG. **12A**. In the display device illustrated in FIG. **15A**, sealing can be performed with the sealing substrate **1031** on which the coloring layers (the red coloring layer **1034R**, the green coloring layer **1034G**, the blue coloring layer **1034B**, and the yellow coloring layer **1034Y**) are provided.

Light emitted through the microcavity and the yellow coloring layer **1034Y** has an emission spectrum in a yellow region. Since yellow is a color with a high luminosity factor, a light-emitting element emitting yellow light has high emission efficiency. Therefore, the display device of FIG. **15A** can reduce power consumption.

FIG. **15A** illustrates the structure provided with the light-emitting elements and the coloring layers for the light-emitting elements as an example; however, the structure is not limited thereto. For example, as shown in FIG. **15B**, a structure including the red coloring layer **1034R**, the green coloring layer **1034G**, and the blue coloring layer **1034B** but not including a yellow coloring layer may be employed to achieve full color display with the four colors of red, green, blue, and yellow or of red, green, blue, and white. The structure as illustrated in FIG. **15A** where the light-emitting elements are provided with the coloring layers is effective to suppress reflection of external light. In contrast, the structure as illustrated in FIG. **15B** where the light-emitting elements are provided with the red coloring layer, the green coloring layer, and the blue coloring layer and without the yellow coloring layer is effective to reduce power consumption because of small energy loss of light emitted from the yellow or white light-emitting element.

STRUCTURE EXAMPLE 5 OF DISPLAY DEVICE

Next, a display device of another embodiment of the present invention is described with reference to FIG. **16**. FIG. **16** is a cross-sectional view taken along the dashed-dotted line A-B and the dashed-dotted line C-D in FIG. **9A**. Note that in FIG. **16**, portions having functions similar to those of portions in FIG. **9B** are given the same reference numerals as in FIG. **9B**, and a detailed description of the portions is omitted.

The display device **600** in FIG. **16** includes a sealing layer **607a**, a sealing layer **607b**, and a sealing layer **607c** in a region **607** surrounded by the element substrate **610**, the sealing substrate **604**, and the sealant **605**. For one or more of the sealing layer **607a**, the sealing layer **607b**, and the sealing layer **607c**, a resin such as a polyvinyl chloride (PVC) based resin, an acrylic-based resin, a polyimide-based resin, an epoxy-based resin, a silicone-based resin, a polyvinyl butyral (PVB) based resin, or an ethylene vinyl acetate (EVA) based resin can be used. Alternatively, an inorganic material such as silicon oxide, silicon oxynitride, silicon nitride oxide, silicon nitride, aluminum oxide, or

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aluminum nitride can be used. The formation of the sealing layers **607a**, **607b**, and **607c** can prevent deterioration of the light-emitting element **618** due to impurities such as water, which is preferable. In the case where the sealing layers **607a**, **607b**, and **607c** are formed, the sealant **605** is not necessarily provided.

Alternatively, any one or two of the sealing layers **607a**, **607b**, and **607c** may be provided or four or more sealing layers may be formed. When the sealing layer has a multilayer structure, the impurities such as water can be effectively prevented from entering the light-emitting element **618** which is inside the display device from the outside of the display device **600**. In the case where the sealing layer has a multilayer structure, a resin and an inorganic material are preferably stacked.

STRUCTURE EXAMPLE 6 OF DISPLAY DEVICE

Although the display devices in the structure examples 1 to 4 in this embodiment each have a structure including optical elements, one embodiment of the present invention does not necessarily include an optical element.

FIGS. **17A** and **17B** each illustrate a display device having a structure in which light is extracted from the sealing substrate **1031** side (a top-emission display device). FIG. **17A** illustrates an example of a display device including a light-emitting layer **1028R**, a light-emitting layer **1028G**, and a light-emitting layer **1028B**. FIG. **17B** illustrates an example of a display device including a light-emitting layer **1028R**, a light-emitting layer **1028G**, a light-emitting layer **1028B**, and a light-emitting layer **1028Y**.

The light-emitting layer **1028R** has a function of exhibiting red light, the light-emitting layer **1028G** has a function of exhibiting green light, and the light-emitting layer **1028B** has a function of exhibiting blue light. The light-emitting layer **1028Y** has a function of exhibiting yellow light or a function of exhibiting light of a plurality of colors selected from blue, green, and red. The light-emitting layer **1028Y** may exhibit white light. Since the light-emitting element which exhibits yellow or white light has high light emission efficiency, the display device including the light-emitting layer **1028Y** can have lower power consumption.

Each of the display devices in FIGS. **17A** and **17B** does not necessarily include coloring layers serving as optical elements because EL layers exhibiting light of different colors are included in sub-pixels.

For the sealing layer **1029**, a resin such as a polyvinyl chloride (PVC) based resin, an acrylic-based resin, a polyimide-based resin, an epoxy-based resin, a silicone-based resin, a polyvinyl butyral (PVB) based resin, or an ethylene vinyl acetate (EVA) based resin can be used. Alternatively, an inorganic material such as silicon oxide, silicon oxynitride, silicon nitride oxide, silicon nitride, aluminum oxide, or aluminum nitride can be used. The formation of the sealing layer **1029** can prevent deterioration of the light-emitting element due to impurities such as water, which is preferable.

Alternatively, the sealing layer **1029** may have a single-layer or two-layer structure, or four or more sealing layers may be formed as the sealing layer **1029**. When the sealing layer has a multilayer structure, the impurities such as water can be effectively prevented from entering the inside of the display device from the outside of the display device. In the case where the sealing layer has a multilayer structure, a resin and an inorganic material are preferably stacked.

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Note that the sealing substrate **1031** has a function of protecting the light-emitting element. Thus, for the sealing substrate **1031**, a flexible substrate or a film can be used.

The structures described in this embodiment can be combined as appropriate with any of the other structures in this embodiment and the other embodiments.

EMBODIMENT 5

In this embodiment, a display device including a light-emitting element of one embodiment of the present invention will be described with reference to FIGS. **18A** and **18B**, FIGS. **19A** and **19B**, and FIGS. **20A** and **20B**.

FIG. **18A** is a block diagram illustrating the display device of one embodiment of the present invention, and FIG. **18B** is a circuit diagram illustrating a pixel circuit of the display device of one embodiment of the present invention.

<Description of Display Device>

The display device illustrated in FIG. **18A** includes a region including pixels of display elements (the region is hereinafter referred to as a pixel portion **802**), a circuit portion provided outside the pixel portion **802** and including circuits for driving the pixels (the portion is hereinafter referred to as a driver circuit portion **804**), circuits having a function of protecting elements (the circuits are hereinafter referred to as protection circuits **806**), and a terminal portion **807**. Note that the protection circuits **806** are not necessarily provided.

A part or the whole of the driver circuit portion **804** is preferably formed over a substrate over which the pixel portion **802** is formed, in which case the number of components and the number of terminals can be reduced. When a part or the whole of the driver circuit portion **804** is not formed over the substrate over which the pixel portion **802** is formed, the part or the whole of the driver circuit portion **804** can be mounted by COG or tape automated bonding (TAB).

The pixel portion **802** includes a plurality of circuits for driving display elements arranged in X rows (X is a natural number of 2 or more) and Y columns (Y is a natural number of 2 or more) (such circuits are hereinafter referred to as pixel circuits **801**). The driver circuit portion **804** includes driver circuits such as a circuit for supplying a signal (scan signal) to select a pixel (the circuit is hereinafter referred to as a scan line driver circuit **804a**) and a circuit for supplying a signal (data signal) to drive a display element in a pixel (the circuit is hereinafter referred to as a signal line driver circuit **804b**).

The scan line driver circuit **804a** includes a shift register or the like. Through the terminal portion **807**, the scan line driver circuit **804a** receives a signal for driving the shift register and outputs a signal. For example, the scan line driver circuit **804a** receives a start pulse signal, a clock signal, or the like and outputs a pulse signal. The scan line driver circuit **804a** has a function of controlling the potentials of wirings supplied with scan signals (such wirings are hereinafter referred to as scan lines GL₁ to GL_X). Note that a plurality of scan line driver circuits **804a** may be provided to control the scan lines GL₁ to GL_X separately. Alternatively, the scan line driver circuit **804a** has a function of supplying an initialization signal. Without being limited thereto, the scan line driver circuit **804a** can supply another signal.

The signal line driver circuit **804b** includes a shift register or the like. The signal line driver circuit **804b** receives a signal (video signal) from which a data signal is derived, as well as a signal for driving the shift register, through the

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terminal portion **807**. The signal line driver circuit **804b** has a function of generating a data signal to be written to the pixel circuit **801** which is based on the video signal. In addition, the signal line driver circuit **804b** has a function of controlling output of a data signal in response to a pulse signal produced by input of a start pulse signal, a clock signal, or the like. Furthermore, the signal line driver circuit **804b** has a function of controlling the potentials of wirings supplied with data signals (such wirings are hereinafter referred to as data lines DL₁ to DL_Y). Alternatively, the signal line driver circuit **804b** has a function of supplying an initialization signal. Without being limited thereto, the signal line driver circuit **804b** can supply another signal.

The signal line driver circuit **804b** includes a plurality of analog switches or the like, for example. The signal line driver circuit **804b** can output, as the data signals, signals obtained by time-dividing the video signal by sequentially turning on the plurality of analog switches. The signal line driver circuit **804b** may include a shift register or the like.

A pulse signal and a data signal are input to each of the plurality of pixel circuits **801** through one of the plurality of scan lines GL supplied with scan signals and one of the plurality of data lines DL supplied with data signals, respectively. Writing and holding of the data signal to and in each of the plurality of pixel circuits **801** are controlled by the scan line driver circuit **804a**. For example, to the pixel circuit **801** in the m-th row and the n-th column (in is a natural number of less than or equal to X, and n is a natural number of less than or equal to Y), a pulse signal is input from the scan line driver circuit **804a** through the scan line GL_m, and a data signal is input from the signal line driver circuit **804b** through the data line DL_n in accordance with the potential of the scan line GL_m.

The protection circuit **806** shown in FIG. **18A** is connected to, for example, the scan line GL between the scan line driver circuit **804a** and the pixel circuit **801**. Alternatively, the protection circuit **806** is connected to the data line DL between the signal line driver circuit **804b** and the pixel circuit **801**. Alternatively, the protection circuit **806** can be connected to a wiring between the scan line driver circuit **804a** and the terminal portion **807**. Alternatively, the protection circuit **806** can be connected to a wiring between the signal line driver circuit **804b** and the terminal portion **807**. Note that the terminal portion **807** means a portion having terminals for inputting power, control signals, and video signals to the display device from external circuits.

The protection circuit **806** is a circuit that electrically connects a wiring connected to the protection circuit to another wiring when a potential out of a certain range is applied to the wiring connected to the protection circuit.

As illustrated in FIG. **18A**, the protection circuits **806** are provided for the pixel portion **802** and the driver circuit portion **804**, so that the resistance of the display device to overcurrent generated by electrostatic discharge (ESD) or the like can be improved. Note that the configuration of the protection circuits **806** is not limited to that, and for example, a configuration in which the protection circuits **806** are connected to the scan line driver circuit **804a** or a configuration in which the protection circuits **806** are connected to the signal line driver circuit **804b** may be employed. Alternatively, the protection circuits **806** may be configured to be connected to the terminal portion **807**.

In FIG. **18A**, an example in which the driver circuit portion **804** includes the scan line driver circuit **804a** and the signal line driver circuit **804b** is shown; however, the structure is not limited thereto. For example, only the scan line driver circuit **804a** may be formed and a separately

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prepared substrate where a signal line driver circuit is formed (e.g., a driver circuit substrate formed with a single crystal semiconductor film or a polycrystalline semiconductor film) may be mounted.

STRUCTURE EXAMPLE OF PIXEL CIRCUIT

Each of the plurality of pixel circuits **801** in FIG. **18A** can have a structure illustrated in FIG. **18B**, for example.

The pixel circuit **801** illustrated in FIG. **18B** includes transistors **852** and **854**, a capacitor **862**, and a light-emitting element **872**.

One of a source electrode and a drain electrode of the transistor **852** is electrically connected to a wiring to which a data signal is supplied (a data line DL_n). A gate electrode of the transistor **852** is electrically connected to a wiring to which a gate signal is supplied (a scan line GL_m).

The transistor **852** has a function of controlling whether to write a data signal.

One of a pair of electrodes of the capacitor **862** is electrically connected to a wiring to which a potential is supplied (hereinafter referred to as a potential supply line VL_a), and the other is electrically connected to the other of the source electrode and the drain electrode of the transistor **852**.

The capacitor **862** functions as a storage capacitor for storing written data.

One of a source electrode and a drain electrode of the transistor **854** is electrically connected to the potential supply line VL_a. Furthermore, a gate electrode of the transistor **854** is electrically connected to the other of the source electrode and the drain electrode of the transistor **852**.

One of an anode and a cathode of the light-emitting element **872** is electrically connected to a potential supply line VL_b, and the other is electrically connected to the other of the source electrode and the drain electrode of the transistor **854**.

As the light-emitting element **872**, any of the light-emitting elements described in Embodiments 1 to 3 can be used.

Note that a high power supply potential VDD is supplied to one of the potential supply line VL_a and the potential supply line VL_b, and a low power supply potential VSS is supplied to the other.

In the display device including the pixel circuits **801** in FIG. **18B**, the pixel circuits **801** are sequentially selected row by row by the scan line driver circuit **804a** in FIG. **18A**, for example, whereby the transistors **852** are turned on and a data signal is written.

When the transistors **852** are turned off, the pixel circuits **801** in which the data has been written are brought into a holding state. Furthermore, the amount of current flowing between the source electrode and the drain electrode of the transistor **854** is controlled in accordance with the potential of the written data signal. The light-emitting element **872** emits light with a luminance corresponding to the amount of flowing current. This operation is sequentially performed row by row; thus, an image is displayed.

Alternatively, the pixel circuit can have a function of compensating variation in threshold voltages or the like of a transistor. FIGS. **19A** and **19B** and FIGS. **20A** and **20B** illustrate examples of the pixel circuit.

The pixel circuit illustrated in FIG. **19A** includes six transistors (transistors **303_1** to **303_6**), a capacitor **304**, and a light-emitting element **305**. The pixel circuit illustrated in FIG. **19A** is electrically connected to wirings **301_1** to

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301_5 and wirings **302_1** and **302_2**. Note that as the transistors **303_1** to **303_6**, for example, p-channel transistors can be used.

The pixel circuit shown in FIG. **19B** has a configuration in which a transistor **303_7** is added to the pixel circuit shown in FIG. **19A**. The pixel circuit illustrated in FIG. **19B** is electrically connected to wirings **301_6** and **301_7**. The wirings **301_5** and **301_6** may be electrically connected to each other. Note that as the transistor **303_7**, for example, a p-channel transistor can be used.

The pixel circuit shown in FIG. **20A** includes six transistors (transistors **308_1** to **308_6**), the capacitor **304**, and the light-emitting element **305**. The pixel circuit illustrated in FIG. **20A** is electrically connected to wirings **306_1** to **306_3** and wirings **307_1** to **307_3**. The wirings **306_1** and **306_3** may be electrically connected to each other. Note that as the transistors **308_1** to **308_6**, for example, p-channel transistors can be used.

The pixel circuit illustrated in FIG. **20B** includes two transistors (transistors **309_1** and **309_2**), two capacitors (capacitors **304_1** and **304_2**), and the light-emitting element **305**. The pixel circuit illustrated in FIG. **20B** is electrically connected to wirings **311_1** to **311_3** and wirings **312_1** and **312_2**. With the configuration of the pixel circuit illustrated in FIG. **20B**, the pixel circuit can be driven by a voltage inputting current driving method (also referred to as CVCC). Note that as the transistors **309_1** and **309_2**, for example, p-channel transistors can be used.

A light-emitting element of one embodiment of the present invention can be used for an active matrix method in which an active element is included in a pixel of a display device or a passive matrix method in which an active element is not included in a pixel of a display device.

In the active matrix method, as an active element (a non-linear element), not only a transistor but also a variety of active elements (non-linear elements) can be used. For example, a metal insulator metal (MIM), a thin film diode (TFD), or the like can also be used. Since these elements can be formed with a smaller number of manufacturing steps, manufacturing cost can be reduced or yield can be improved. Alternatively, since the size of these elements is small, the aperture ratio can be improved, so that power consumption can be reduced and higher luminance can be achieved.

As a method other than the active matrix method, the passive matrix method in which an active element (a non-linear element) is not used can also be used. Since an active element (a non-linear element) is not used, the number of manufacturing steps is small, so that manufacturing cost can be reduced or yield can be improved. Alternatively, since an active element (a non-linear element) is not used, the aperture ratio can be improved, so that power consumption can be reduced or higher luminance can be achieved, for example.

The structure described in this embodiment can be used in combination with any of the structures described in the other embodiments as appropriate.

EMBODIMENT 6

In this embodiment, a display device including a light-emitting element of one embodiment of the present invention and an electronic device in which the display device is provided with an input device will be described with reference to FIGS. **21A** and **21B**, FIGS. **22A** to **22C**, FIGS. **23A** and **23B**, FIGS. **24A** and **24B**, and FIG. **25**.

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<Description 1 of Touch Panel>

In this embodiment, a touch panel **2000** including a display device and an input device will be described as an example of an electronic device. In addition, an example in which a touch sensor is included as an input device will be described.

FIGS. **21A** and **21B** are perspective views of the touch panel **2000**. Note that FIGS. **21A** and **21B** illustrate only main components of the touch panel **2000** for simplicity.

The touch panel **2000** includes a display device **2501** and a touch sensor **2595** (see FIG. **21B**). The touch panel **2000** also includes a substrate **2510**, a substrate **2570**, and a substrate **2590**. The substrate **2510**, the substrate **2570**, and the substrate **2590** each have flexibility. Note that one or all of the substrates **2510**, **2570**, and **2590** may be inflexible.

The display device **2501** includes a plurality of pixels over the substrate **2510** and a plurality of wirings **2511** through which signals are supplied to the pixels. The plurality of wirings **2511** are led to a peripheral portion of the substrate **2510**, and parts of the plurality of wirings **2511** form a terminal **2519**. The terminal **2519** is electrically connected to an FPC **2509(1)**. The plurality of wirings **2511** can supply signals from a signal line driver circuit **2503s(1)** to the plurality of pixels.

The substrate **2590** includes the touch sensor **2595** and a plurality of wirings **2598** electrically connected to the touch sensor **2595**. The plurality of wirings **2598** are led to a peripheral portion of the substrate **2590**, and parts of the plurality of wirings **2598** form a terminal. The terminal is electrically connected to an FPC **2509(2)**. Note that in FIG. **21B**, electrodes, wirings, and the like of the touch sensor **2595** provided on the back side of the substrate **2590** (the side facing the substrate **2510**) are indicated by solid lines for clarity.

As the touch sensor **2595**, a capacitive touch sensor can be used. Examples of the capacitive touch sensor are a surface capacitive touch sensor and a projected capacitive touch sensor.

Examples of the projected capacitive touch sensor are a self capacitive touch sensor and a mutual capacitive touch sensor, which differ mainly in the driving method. The use of a mutual capacitive type is preferable because multiple points can be sensed simultaneously.

Note that the touch sensor **2595** illustrated in FIG. **21B** is an example of using a projected capacitive touch sensor.

Note that a variety of sensors that can sense proximity or touch of a sensing target such as a finger can be used as the touch sensor **2595**.

The projected capacitive touch sensor **2595** includes electrodes **2591** and electrodes **2592**. The electrodes **2591** are electrically connected to any of the plurality of wirings **2598**, and the electrodes **2592** are electrically connected to any of the other wirings **2598**.

The electrodes **2592** each have a shape of a plurality of quadrangles arranged in one direction with one corner of a quadrangle connected to one corner of another quadrangle as illustrated in FIGS. **21A** and **21B**.

The electrodes **2591** each have a quadrangular shape and are arranged in a direction intersecting with the direction in which the electrodes **2592** extend.

A wiring **2594** electrically connects two electrodes **2591** between which the electrode **2592** is positioned. The intersecting area of the electrode **2592** and the wiring **2594** is preferably as small as possible. Such a structure allows a reduction in the area of a region where the electrodes are not

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provided, reducing variation in transmittance. As a result, variation in luminance of light passing through the touch sensor **2595** can be reduced.

Note that the shapes of the electrodes **2591** and the electrodes **2592** are not limited thereto and can be any of a variety of shapes. For example, a structure may be employed in which the plurality of electrodes **2591** are arranged so that gaps between the electrodes **2591** are reduced as much as possible, and the electrodes **2592** are spaced apart from the electrodes **2591** with an insulating layer interposed therebetween to have regions not overlapping with the electrodes **2591**. In this case, it is preferable to provide, between two adjacent electrodes **2592**, a dummy electrode electrically insulated from these electrodes because the area of regions having different transmittances can be reduced.

<Description of Display Device>

Next, the display device **2501** will be described in detail with reference to FIG. **22A**. FIG. **22A** corresponds to a cross-sectional view taken along dashed-dotted line X1-X2 in FIG. **21B**.

The display device **2501** includes a plurality of pixels arranged in a matrix. Each of the pixels includes a display element and a pixel circuit for driving the display element.

In the following description, an example of using a light-emitting element that emits white light as a display element will be described; however, the display element is not limited to such an element. For example, light-emitting elements that emit light of different colors may be included so that the light of different colors can be emitted from adjacent pixels.

For the substrate **2510** and the substrate **2570**, for example, a flexible material with a vapor permeability of lower than or equal to $1 \times 10^{-5} \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$, preferably lower than or equal to $1 \times 10^{-6} \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ can be favorably used. Alternatively, materials whose thermal expansion coefficients are substantially equal to each other are preferably used for the substrate **2510** and the substrate **2570**. For example, the coefficients of linear expansion of the materials are preferably lower than or equal to $1 \times 10^{-3} / \text{K}$, further preferably lower than or equal to $5 \times 10^{-5} / \text{K}$, and still further preferably lower than or equal to $1 \times 10^{-5} / \text{K}$.

Note that the substrate **2510** is a stacked body including an insulating layer **2510a** for preventing impurity diffusion into the light-emitting element, a flexible substrate **2510b**, and an adhesive layer **2510c** for attaching the insulating layer **2510a** and the flexible substrate **2510b** to each other. The substrate **2570** is a stacked body including an insulating layer **2570a** for preventing impurity diffusion into the light-emitting element, a flexible substrate **2570b**, and an adhesive layer **2570c** for attaching the insulating layer **2570a** and the flexible substrate **2570b** to each other.

For the adhesive layer **2510c** and the adhesive layer **2570c**, for example, polyester, polyolefin, polyamide (e.g., nylon, aramid), polyimide, polycarbonate, or an acrylic resin, polyurethane, or an epoxy resin can be used. Alternatively, a material that includes a resin having a siloxane bond such as silicone can be used.

A sealing layer **2560** is provided between the substrate **2510** and the substrate **2570**. The sealing layer **2560** preferably has a refractive index higher than that of air. In the case where light is extracted to the sealing layer **2560** side as illustrated in FIG. **22A**, the sealing layer **2560** can also serve as an optical adhesive layer.

A sealant may be formed in the peripheral portion of the sealing layer **2560**. With the use of the sealant, a light-emitting element **2550R** can be provided in a region surrounded by the substrate **2510**, the substrate **2570**, the

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sealing layer **2560**, and the sealant. Note that an inert gas (such as nitrogen and argon) may be used instead of the sealing layer **2560**. A drying agent may be provided in the inert gas so as to adsorb moisture or the like. A resin such as an acrylic resin or an epoxy resin may be used. An epoxy-based resin or a glass frit is preferably used as the sealant. As a material used for the sealant, a material which is impermeable to moisture and oxygen is preferably used.

The display device **2501** includes a pixel **2502R**. The pixel **2502R** includes a light-emitting module **2580R**.

The pixel **2502R** includes the light-emitting element **2550R** and a transistor **2502t** that can supply electric power to the light-emitting element **2550R**. Note that the transistor **2502t** functions as part of the pixel circuit. The light-emitting module **2580R** includes the light-emitting element **2550R** and a coloring layer **2567R**.

The light-emitting element **2550R** includes a lower electrode, an upper electrode, and an EL layer between the lower electrode and the upper electrode. As the light-emitting element **2550R**, any of the light-emitting elements described in Embodiments 1 to 3 can be used.

A microcavity structure may be employed between the lower electrode and the upper electrode so as to increase the intensity of light having a specific wavelength.

In the case where the sealing layer **2560** is provided on the light extraction side, the sealing layer **2560** is in contact with the light-emitting element **2550R** and the coloring layer **2567R**.

The coloring layer **2567R** is positioned in a region overlapping with the light-emitting element **2550R**. Accordingly, part of light emitted from the light-emitting element **2550R** passes through the coloring layer **2567R** and is emitted to the outside of the light-emitting module **2580R** as indicated by an arrow in the drawing.

The display device **2501** includes a light-blocking layer **2567BM** on the light extraction side. The light-blocking layer **2567BM** is provided so as to surround the coloring layer **2567R**.

The coloring layer **2567R** is a coloring layer having a function of transmitting light in a particular wavelength region. For example, a color filter for transmitting light in a red wavelength region, a color filter for transmitting light in a green wavelength region, a color filter for transmitting light in a blue wavelength region, a color filter for transmitting light in a yellow wavelength region, or the like can be used. Each color filter can be formed with any of various materials by a printing method, an inkjet method, an etching method using a photolithography technique, or the like.

An insulating layer **2521** is provided in the display device **2501**. The insulating layer **2521** covers the transistor **2502t**. Note that the insulating layer **2521** has a function of covering unevenness caused by the pixel circuit. The insulating layer **2521** may have a function of suppressing impurity diffusion. This can prevent the reliability of the transistor **2502t** or the like from being lowered by impurity diffusion.

The light-emitting element **2550R** is formed over the insulating layer **2521**. A partition **2528** is provided so as to overlap with an end portion of the lower electrode of the light-emitting element **2550R**. Note that a spacer for controlling the distance between the substrate **2510** and the substrate **2570** may be formed over the partition **2528**.

A scan line driver circuit **2503g(1)** includes a transistor **2503t** and a capacitor **2503c**. Note that the driver circuit can be formed in the same process and over the same substrate as those of the pixel circuits.

The wirings **2511** through which signals can be supplied are provided over the substrate **2510**. The terminal **2519** is

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provided over the wirings **2511**. The FPC **2509(1)** is electrically connected to the terminal **2519**. The FPC **2509(1)** has a function of supplying a video signal, a clock signal, a start signal, a reset signal, or the like. Note that the FPC **2509(1)** may be provided with a PWB.

In the display device **2501**, transistors with any of a variety of structures can be used. FIG. **22A** illustrates an example of using bottom-gate transistors; however, the present invention is not limited to this example, and top-gate transistors may be used in the display device **2501** as illustrated in FIG. **22B**.

In addition, there is no particular limitation on the polarity of the transistor **2502t** and the transistor **2503t**. For these transistors, n-channel and p-channel transistors may be used, or either n-channel transistors or p-channel transistors may be used, for example. Furthermore, there is no particular limitation on the crystallinity of a semiconductor film used for the transistors **2502t** and **2503t**. For example, an amorphous semiconductor film or a crystalline semiconductor film may be used. Examples of semiconductor materials include Group 14 semiconductors (e.g., a semiconductor including silicon), compound semiconductors (including oxide semiconductors), organic semiconductors, and the like. An oxide semiconductor that has an energy gap of 2 eV or more, preferably 2.5 eV or more, further preferably 3 eV or more is preferably used for one of the transistors **2502t** and **2503t** or both, so that the off-state current of the transistors can be reduced. Examples of the oxide semiconductors include an In—Ga oxide, an In—M—Zn oxide (M represents Al, Ga, Y, Zr, La, Ce, Sn, Hf, or Nd), and the like. <Description of Touch Sensor>

Next, the touch sensor **2595** will be described in detail with reference to FIG. **22C**. FIG. **22C** corresponds to a cross-sectional view taken along dashed-dotted line X3-X4 in FIG. **21B**.

The touch sensor **2595** includes the electrodes **2591** and the electrodes **2592** provided in a staggered arrangement on the substrate **2590**, an insulating layer **2593** covering the electrodes **2591** and the electrodes **2592**, and the wiring **2594** that electrically connects the adjacent electrodes **2591** to each other.

The electrodes **2591** and the electrodes **2592** are formed using a light-transmitting conductive material. As a light-transmitting conductive material, a conductive oxide such as indium oxide, indium tin oxide, indium zinc oxide, zinc oxide, or zinc oxide to which gallium is added can be used. Note that a film including graphene may be used as well. The film including graphene can be formed, for example, by reducing a film containing graphene oxide. As a reducing method, a method with application of heat or the like can be employed.

The electrodes **2591** and the electrodes **2592** may be formed by, for example, depositing a light-transmitting conductive material on the substrate **2590** by a sputtering method and then removing an unnecessary portion by any of various pattern forming techniques such as photolithography.

Examples of a material for the insulating layer **2593** are a resin such as an acrylic resin or an epoxy resin, a resin having a siloxane bond, and an inorganic insulating material such as silicon oxide, silicon oxynitride, or aluminum oxide.

Openings reaching the electrodes **2591** are formed in the insulating layer **2593**, and the wiring **2594** electrically connects the adjacent electrodes **2591**. A light-transmitting conductive material can be favorably used as the wiring **2594** because the aperture ratio of the touch panel can be increased. Moreover, a material with higher conductivity

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than the conductivities of the electrodes **2591** and **2592** can be favorably used for the wiring **2594** because electric resistance can be reduced.

One electrode **2592** extends in one direction, and a plurality of electrodes **2592** are provided in the form of stripes. The wiring **2594** intersects with the electrode **2592**.

Adjacent electrodes **2591** are provided with one electrode **2592** provided therebetween. The wiring **2594** electrically connects the adjacent electrodes **2591**.

Note that the plurality of electrodes **2591** are not necessarily arranged in the direction orthogonal to one electrode **2592** and may be arranged to intersect with one electrode **2592** at an angle of more than 0 degrees and less than 90 degrees.

The wiring **2598** is electrically connected to any of the electrodes **2591** and **2592**. Part of the wiring **2598** functions as a terminal. For the wiring **2598**, a metal material such as aluminum, gold, platinum, silver, nickel, titanium, tungsten, chromium, molybdenum, iron, cobalt, copper, or palladium or an alloy material containing any of these metal materials can be used.

Note that an insulating layer that covers the insulating layer **2593** and the wiring **2594** may be provided to protect the touch sensor **2595**.

A connection layer **2599** electrically connects the wiring **2598** to the FPC **2509(2)**.

As the connection layer **2599**, any of various anisotropic conductive films (ACF), anisotropic conductive pastes (ACP), or the like can be used.

<Description 2 of Touch Panel>

Next, the touch panel **2000** will be described in detail with reference to FIG. **23A**. FIG. **23A** corresponds to a cross-sectional view taken along dashed-dotted line X5-X6 in FIG. **21A**.

In the touch panel **2000** illustrated in FIG. **23A**, the display device **2501** described with reference to FIG. **22A** and the touch sensor **2595** described with reference to FIG. **22C** are attached to each other.

The touch panel **2000** illustrated in FIG. **23A** includes an adhesive layer **2597** and an anti-reflective layer **2567p** in addition to the components described with reference to FIGS. **22A** and **22C**.

The adhesive layer **2597** is provided in contact with the wiring **2594**. Note that the adhesive layer **2597** attaches the substrate **2590** to the substrate **2570** so that the touch sensor **2595** overlaps with the display device **2501**. The adhesive layer **2597** preferably has a light-transmitting property. A heat curable resin or an ultraviolet curable resin can be used for the adhesive layer **2597**. For example, an acrylic resin, a urethane-based resin, an epoxy-based resin, or a siloxane-based resin can be used.

The anti-reflective layer **2567p** is positioned in a region overlapping with pixels. As the anti-reflective layer **2567p**, a circularly polarizing plate can be used, for example.

Next, a touch panel having a structure different from that illustrated in FIG. **23A** will be described with reference to FIG. **23B**.

FIG. **23B** is a cross-sectional view of a touch panel **2001**. The touch panel **2001** illustrated in FIG. **23B** differs from the touch panel **2000** illustrated in FIG. **23A** in the position of the touch sensor **2595** relative to the display device **2501**. Different parts are described in detail below, and the above description of the touch panel **2000** is referred to for the other similar parts.

The coloring layer **2567R** is positioned in a region overlapping with the light-emitting element **2550R**. The light-emitting element **2550R** illustrated in FIG. **23B** emits light

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to the side where the transistor **2502t** is provided. Accordingly, part of light emitted from the light-emitting element **2550R** passes through the coloring layer **2567R** and is emitted to the outside of the light-emitting module **2580R** as indicated by an arrow in FIG. **23B**.

The touch sensor **2595** is provided on the substrate **2510** side of the display device **2501**.

The adhesive layer **2597** is provided between the substrate **2510** and the substrate **2590** and attaches the touch sensor **2595** to the display device **2501**.

As illustrated in FIG. **23A** or **23B**, light may be emitted from the light-emitting element through one or both of the substrate **2510** and the substrate **2570**.

<Description of Method for Driving Touch Panel>

Next, an example of a method for driving a touch panel will be described with reference to FIGS. **24A** and **24B**.

FIG. **24A** is a block diagram illustrating the structure of a mutual capacitive touch sensor. FIG. **24A** illustrates a pulse voltage output circuit **2601** and a current sensing circuit **2602**. Note that in FIG. **24A**, six wirings X1 to X6 represent the electrodes **2621** to which a pulse voltage is applied, and six wirings Y1 to Y6 represent the electrodes **2622** that detect changes in current. FIG. **24A** also illustrates capacitors **2603** that are each formed in a region where the electrodes **2621** and **2622** overlap with each other. Note that functional replacement between the electrodes **2621** and **2622** is possible.

The pulse voltage output circuit **2601** is a circuit for sequentially applying a pulse voltage to the wirings X1 to X6. By application of a pulse voltage to the wirings X1 to X6, an electric field is generated between the electrodes **2621** and **2622** of the capacitor **2603**. When the electric field between the electrodes is shielded, for example, a change occurs in the capacitor **2603** (mutual capacitance). The approach or contact of a sensing target can be sensed by utilizing this change.

The current sensing circuit **2602** is a circuit for detecting changes in current flowing through the wirings Y1 to Y6 that are caused by the change in mutual capacitance in the capacitor **2603**. No change in current value is detected in the wirings Y1 to Y6 when there is no approach or contact of a sensing target, whereas a decrease in current value is detected when mutual capacitance is decreased owing to the approach or contact of a sensing target. Note that an integrator circuit or the like is used for sensing of current values.

FIG. **24B** is a timing chart showing input and output waveforms in the mutual capacitive touch sensor illustrated in FIG. **24A**. In FIG. **24B**, sensing of a sensing target is performed in all the rows and columns in one frame period. FIG. **24B** shows a period when a sensing target is not sensed (not touched) and a period when a sensing target is sensed (touched). In FIG. **24B**, sensed current values of the wirings Y1 to Y6 are shown as the waveforms of voltage values.

A pulse voltage is sequentially applied to the wirings X1 to X6, and the waveforms of the wirings Y1 to Y6 change in accordance with the pulse voltage. When there is no approach or contact of a sensing target, the waveforms of the wirings Y1 to Y6 change in accordance with changes in the voltages of the wirings X1 to X6. The current value is decreased at the point of approach or contact of a sensing target and accordingly the waveform of the voltage value changes.

By detecting a change in mutual capacitance in this manner, the approach or contact of a sensing target can be sensed.

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<Description of Sensor Circuit>

Although FIG. 24A illustrates a passive matrix type touch sensor in which only the capacitor 2603 is provided at the intersection of wirings as a touch sensor, an active matrix type touch sensor including a transistor and a capacitor may be used. FIG. 25 illustrates an example of a sensor circuit included in an active matrix type touch sensor.

The sensor circuit in FIG. 25 includes the capacitor 2603 and transistors 2611, 2612, and 2613.

A signal G2 is input to a gate of the transistor 2613. A voltage VRES is applied to one of a source and a drain of the transistor 2613, and one electrode of the capacitor 2603 and a gate of the transistor 2611 are electrically connected to the other of the source and the drain of the transistor 2613. One of a source and a drain of the transistor 2611 is electrically connected to one of a source and a drain of the transistor 2612, and a voltage VSS is applied to the other of the source and the drain of the transistor 2611. A signal G1 is input to a gate of the transistor 2612, and a wiring ML is electrically connected to the other of the source and the drain of the transistor 2612. The voltage VSS is applied to the other electrode of the capacitor 2603.

Next, the operation of the sensor circuit in FIG. 25 will be described. First, a potential for turning on the transistor 2613 is supplied as the signal G2, and a potential with respect to the voltage VRES is thus applied to the node n connected to the gate of the transistor 2611. Then, a potential for turning off the transistor 2613 is applied as the signal G2, whereby the potential of the node n is maintained.

Then, mutual capacitance of the capacitor 2603 changes owing to the approach or contact of a sensing target such as a finger, and accordingly the potential of the node n is changed from VRES.

In reading operation, a potential for turning on the transistor 2612 is supplied as the signal G1. A current flowing through the transistor 2611, that is, a current flowing through the wiring ML is changed in accordance with the potential of the node n. By sensing this current, the approach or contact of a sensing target can be sensed.

In each of the transistors 2611, 2612, and 2613, an oxide semiconductor layer is preferably used as a semiconductor layer in which a channel region is formed. In particular, such a transistor is preferably used as the transistor 2613 so that the potential of the node n can be held for a long time and the frequency of operation of resupplying VRES to the node n (refresh operation) can be reduced.

The structure described in this embodiment can be used in combination with any of the structures described in the other embodiments as appropriate.

EMBODIMENT 7

In this embodiment, a display module and electronic devices including a light-emitting element of one embodiment of the present invention will be described with reference to FIG. 26, FIGS. 27A to 27G, FIGS. 28A to 28D, and FIGS. 29A and 29B.

<Display Module>

In a display module 8000 in FIG. 26, a touch sensor 8004 connected to an FPC 8003, a display device 8006 connected to an FPC 8005, a frame 8009, a printed board 8010, and a battery 8011 are provided between an upper cover 8001 and a lower cover 8002.

The light-emitting element of one embodiment of the present invention can be used for the display device 8006, for example.

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The shapes and sizes of the upper cover 8001 and the lower cover 8002 can be changed as appropriate in accordance with the sizes of the touch sensor 8004 and the display device 8006.

The touch sensor 8004 can be a resistive touch sensor or a capacitive touch sensor and may be formed to overlap with the display device 8006. A counter substrate (sealing substrate) of the display device 8006 can have a touch sensor function. A photosensor may be provided in each pixel of the display device 8006 so that an optical touch sensor is obtained.

The frame 8009 protects the display device 8006 and also serves as an electromagnetic shield for blocking electromagnetic waves generated by the operation of the printed board 8010. The frame 8009 may serve as a radiator plate.

The printed board 8010 has a power supply circuit and a signal processing circuit for outputting a video signal and a clock signal. As a power source for supplying power to the power supply circuit, an external commercial power source or the battery 8011 provided separately may be used. The battery 8011 can be omitted in the case of using a commercial power source.

The display module 8000 can be additionally provided with a member such as a polarizing plate, a retardation plate, or a prism sheet.

<Electronic Device>

FIGS. 27A to 27G illustrate electronic devices. These electronic devices can include a housing 9000, a display portion 9001, a speaker 9003, operation keys 9005 (including a power switch or an operation switch), a connection terminal 9006, a sensor 9007 (a sensor having a function of measuring or sensing force, displacement, position, speed, acceleration, angular velocity, rotational frequency, distance, light, liquid, magnetism, temperature, chemical substance, sound, time, hardness, electric field, current, voltage, electric power, radiation, flow rate, humidity, gradient, oscillation, odor, or infrared ray), a microphone 9008, and the like. In addition, the sensor 9007 may have a function of measuring biological information like a pulse sensor and a finger print sensor.

The electronic devices illustrated in FIGS. 27A to 27G can have a variety of functions, for example, a function of displaying a variety of data (a still image, a moving image, a text image, and the like) on the display portion, a touch sensor function, a function of displaying a calendar, date, time, and the like, a function of controlling a process with a variety of software (programs), a wireless communication function, a function of being connected to a variety of computer networks with a wireless communication function, a function of transmitting and receiving a variety of data with a wireless communication function, a function of reading a program or data stored in a memory medium and displaying the program or data on the display portion, and the like. Note that functions that can be provided for the electronic devices illustrated in FIGS. 27A to 27G are not limited to those described above, and the electronic devices can have a variety of functions. Although not illustrated in FIGS. 27A to 27G, the electronic devices may include a plurality of display portions. The electronic devices may have a camera or the like and a function of taking a still image, a function of taking a moving image, a function of storing the taken image in a memory medium (an external memory medium or a memory medium incorporated in the camera), a function of displaying the taken image on the display portion, or the like.

The electronic devices illustrated in FIGS. 27A to 27G will be described in detail below.

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FIG. 27A is a perspective view of a portable information terminal 9100. The display portion 9001 of the portable information terminal 9100 is flexible. Therefore, the display portion 9001 can be incorporated along a bent surface of a bent housing 9000. In addition, the display portion 9001 includes a touch sensor, and operation can be performed by touching the screen with a finger, a stylus, or the like. For example, when an icon displayed on the display portion 9001 is touched, an application can be started.

FIG. 27B is a perspective view of a portable information terminal 9101. The portable information terminal 9101 functions as, for example, one or more of a telephone set, a notebook, and an information browsing system. Specifically, the portable information terminal can be used as a smart-phone. Note that the speaker 9003, the connection terminal 9006, the sensor 9007, and the like, which are not shown in FIG. 27B, can be positioned in the portable information terminal 9101 as in the portable information terminal 9100 shown in FIG. 27A. The portable information terminal 9101 can display characters and image information on its plurality of surfaces. For example, three operation buttons 9050 (also referred to as operation icons, or simply, icons) can be displayed on one surface of the display portion 9001. Furthermore, information 9051 indicated by dashed rectangles can be displayed on another surface of the display portion 9001. Examples of the information 9051 include display indicating reception of an incoming email, social networking service (SNS) message, call, and the like; the title and sender of an email and SNS message; the date; the time; remaining battery; and the reception strength of an antenna. Instead of the information 9051, the operation buttons 9050 or the like may be displayed on the position where the information 9051 is displayed.

FIG. 27C is a perspective view of a portable information terminal 9102. The portable information terminal 9102 has a function of displaying information on three or more surfaces of the display portion 9001. Here, information 9052, information 9053, and information 9054 are displayed on different surfaces. For example, a user of the portable information terminal 9102 can see the display (here, the information 9053) with the portable information terminal 9102 put in a breast pocket of his/her clothes. Specifically, a caller's phone number, name, or the like of an incoming call is displayed in a position that can be seen from above the portable information terminal 9102. Thus, the user can see the display without taking out the portable information terminal 9102 from the pocket and decide whether to answer the call.

FIG. 27D is a perspective view of a watch-type portable information terminal 9200. The portable information terminal 9200 is capable of executing a variety of applications such as mobile phone calls, e-mailing, viewing and editing texts, music reproduction, Internet communication, and computer games. The display surface of the display portion 9001 is bent, and images can be displayed on the bent display surface. The portable information terminal 9200 can employ near field communication that is a communication method based on an existing communication standard. In that case, for example, mutual communication between the portable information terminal 9200 and a headset capable of wireless communication can be performed, and thus hands-free calling is possible. The portable information terminal 9200 includes the connection terminal 9006, and data can be directly transmitted to and received from another information terminal via a connector. Power charging through the connection terminal 9006 is possible. Note that the charging

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operation may be performed by wireless power feeding without using the connection terminal 9006.

FIGS. 27E, 27F, and 27G are perspective views of a foldable portable information terminal 9201. FIG. 27E is a perspective view illustrating the portable information terminal 9201 that is opened. FIG. 27F is a perspective view illustrating the portable information terminal 9201 that is being opened or being folded. FIG. 27G is a perspective view illustrating the portable information terminal 9201 that is folded. The portable information terminal 9201 is highly portable when folded. When the portable information terminal 9201 is opened, a seamless large display region is highly browsable. The display portion 9001 of the portable information terminal 9201 is supported by three housings 9000 joined together by hinges 9055. By folding the portable information terminal 9201 at a connection portion between two housings 9000 with the hinges 9055, the portable information terminal 9201 can be reversibly changed in shape from an opened state to a folded state. For example, the portable information terminal 9201 can be bent with a radius of curvature of greater than or equal to 1 mm and less than or equal to 150 mm.

Examples of electronic devices are a television set (also referred to as a television or a television receiver), a monitor of a computer or the like, a camera such as a digital camera or a digital video camera, a digital photo frame, a mobile phone handset (also referred to as a mobile phone or a mobile phone device), a goggle-type display (head mounted display), a portable game machine, a portable information terminal, an audio reproducing device, and a large-sized game machine such as a pachinko machine.

FIG. 28A illustrates an example of a television set. In the television set 9300, the display portion 9001 is incorporated into the housing 9000. Here, the housing 9000 is supported by a stand 9301.

The television set 9300 illustrated in FIG. 28A can be operated with an operation switch of the housing 9000 or a separate remote controller 9311. The display portion 9001 may include a touch sensor. The television set 9300 can be operated by touching the display portion 9001 with a finger or the like. The remote controller 9311 may be provided with a display portion for displaying data output from the remote controller 9311. With operation keys or a touch panel of the remote controller 9311, channels or volume can be controlled and images displayed on the display portion 9001 can be controlled.

The television set 9300 is provided with a receiver, a modem, or the like. A general television broadcast can be received with the receiver. When the television set is connected to a communication network with or without wires via the modem, one-way (from a transmitter to a receiver) or two-way (between a transmitter and a receiver or between receivers) data communication can be performed.

The electronic device or the lighting device of one embodiment of the present invention has flexibility and therefore can be incorporated along a curved inside/outside wall surface of a house or a building or a curved interior/exterior surface of a car.

FIG. 28B is an external view of an automobile 9700. FIG. 28C illustrates a driver's seat of the automobile 9700. The automobile 9700 includes a car body 9701, wheels 9702, a dashboard 9703, lights 9704, and the like. The display device, the light-emitting device, or the like of one embodiment of the present invention can be used in a display portion or the like of the automobile 9700. For example, the display device, the light-emitting device, or the like of one

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embodiment of the present invention can be used in display portions **9710** to **9715** illustrated in FIG. **28C**.

The display portion **9710** and the display portion **9711** are each a display device provided in an automobile windshield. The display device, the light-emitting device, or the like of one embodiment of the present invention can be a see-through display device, through which the opposite side can be seen, using a light-transmitting conductive material for its electrodes and wirings. Such a see-through display portion **9710** or **9711** does not hinder driver's vision during driving the automobile **9700**. Thus, the display device, the light-emitting device, or the like of one embodiment of the present invention can be provided in the windshield of the automobile **9700**. Note that in the case where a transistor or the like for driving the display device, the light-emitting device, or the like is provided, a transistor having a light-transmitting property, such as an organic transistor using an organic semiconductor material or a transistor using an oxide semiconductor, is preferably used.

The display portion **9712** is a display device provided on a pillar portion. For example, an image taken by an imaging unit provided in the car body is displayed on the display portion **9712**, whereby the view hindered by the pillar portion can be compensated. The display portion **9713** is a display device provided on the dashboard. For example, an image taken by an imaging unit provided in the car body is displayed on the display portion **9713**, whereby the view hindered by the dashboard can be compensated. That is, by displaying an image taken by an imaging unit provided on the outside of the automobile, blind areas can be eliminated and safety can be increased. Displaying an image to compensate for the area which a driver cannot see, makes it possible for the driver to confirm safety easily and comfortably.

FIG. **28D** illustrates the inside of a car in which bench seats are used for a driver seat and a front passenger seat. A display portion **9721** is a display device provided in a door portion. For example, an image taken by an imaging unit provided in the car body is displayed on the display portion **9721**, whereby the view hindered by the door can be compensated. A display portion **9722** is a display device provided in a steering wheel. A display portion **9723** is a display device provided in the middle of a seating face of the bench seat. Note that the display device can be used as a seat heater by providing the display device on the seating face or backrest and by using heat generation of the display device as a heat source.

The display portion **9714**, the display portion **9715**, and the display portion **9722** can provide a variety of kinds of information such as navigation data, a speedometer, a tachometer, a mileage, a fuel meter, a gearshift indicator, and air-condition setting. The content, layout, or the like of the display on the display portions can be changed freely by a user as appropriate. The information listed above can also be displayed on the display portions **9710** to **9713**, **9721**, and **9723**. The display portions **9710** to **9715** and **9721** to **9723** can also be used as lighting devices. The display portions **9710** to **9715** and **9721** to **9723** can also be used as heating devices.

Furthermore, the electronic device of one embodiment of the present invention may include a secondary battery. It is preferable that the secondary battery be capable of being charged by non-contact power transmission.

Examples of the secondary battery include a lithium ion secondary battery such as a lithium polymer battery using a gel electrolyte (lithium ion polymer battery), a lithium-ion battery, a nickel-hydride battery, a nickel-cadmium battery,

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an organic radical battery, a lead-acid battery, an air secondary battery, a nickel-zinc battery, and a silver-zinc battery.

The electronic device of one embodiment of the present invention may include an antenna. When a signal is received by the antenna, the electronic device can display an image, data, or the like on a display portion. When the electronic device includes a secondary battery, the antenna may be used for contactless power transmission.

A display device **9500** illustrated in FIGS. **29A** and **29B** includes a plurality of display panels **9501**, a hinge **9511**, and a bearing **9512**. The plurality of display panels **9501** each include a display region **9502** and a light-transmitting region **9503**.

Each of the plurality of display panels **9501** is flexible. Two adjacent display panels **9501** are provided so as to partly overlap with each other. For example, the light-transmitting regions **9503** of the two adjacent display panels **9501** can be overlapped each other. A display device having a large screen can be obtained with the plurality of display panels **9501**. The display device is highly versatile because the display panels **9501** can be wound depending on its use.

Moreover, although the display regions **9502** of the adjacent display panels **9501** are separated from each other in FIGS. **29A** and **29B**, without limitation to this structure, the display regions **9502** of the adjacent display panels **9501** may overlap with each other without any space so that a continuous display region **9502** is obtained, for example.

The electronic devices described in this embodiment each include the display portion for displaying some sort of data. Note that the light-emitting element of one embodiment of the present invention can also be used for an electronic device which does not have a display portion. The structure in which the display portion of the electronic device described in this embodiment is flexible and display can be performed on the bent display surface or the structure in which the display portion of the electronic device is foldable is described as an example; however, the structure is not limited thereto and a structure in which the display portion of the electronic device is not flexible and display is performed on a plane portion may be employed.

The structure described in this embodiment can be used in combination with any of the structures described in the other embodiments as appropriate.

EMBODIMENT 8

In this embodiment, a light-emitting device including the light-emitting element of one embodiment of the present invention will be described with reference to FIGS. **30A** to **30C** and FIGS. **31A** to **31D**.

FIG. **30A** is a perspective view of a light-emitting device **3000** shown in this embodiment, and FIG. **30B** is a cross-sectional view along dashed-dotted line E-F in FIG. **30A**. Note that in FIG. **30A**, some components are illustrated by broken lines in order to avoid complexity of the drawing.

The light-emitting device **3000** illustrated in FIGS. **30A** and **30B** includes a substrate **3001**, a light-emitting element **3005** over the substrate **3001**, a first sealing region **3007** provided around the light-emitting element **3005**, and a second sealing region **3009** provided around the first sealing region **3007**.

Light is emitted from the light-emitting element **3005** through one or both of the substrate **3001** and a substrate **3003**. In FIGS. **30A** and **30B**, a structure in which light is emitted from the light-emitting element **3005** to the lower side (the substrate **3001** side) is illustrated.

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As illustrated in FIGS. 30A and 30B, the light-emitting device 3000 has a double sealing structure in which the light-emitting element 3005 is surrounded by the first sealing region 3007 and the second sealing region 3009. With the double sealing structure, entry of impurities (e.g., water, oxygen, and the like) from the outside into the light-emitting element 3005 can be favorably suppressed. Note that it is not necessary to provide both the first sealing region 3007 and the second sealing region 3009. For example, only the first sealing region 3007 may be provided.

Note that in FIG. 30B, the first sealing region 3007 and the second sealing region 3009 are each provided in contact with the substrate 3001 and the substrate 3003. However, without limitation to such a structure, for example, one or both of the first sealing region 3007 and the second sealing region 3009 may be provided in contact with an insulating film or a conductive film provided on the substrate 3001. Alternatively, one or both of the first sealing region 3007 and the second sealing region 3009 may be provided in contact with an insulating film or a conductive film provided on the substrate 3003.

The substrate 3001 and the substrate 3003 can have structures similar to those of the substrate 200 and the substrate 220 described in the above embodiment, respectively. The light-emitting element 3005 can have a structure similar to that of any of the light-emitting elements described in the above embodiments.

For the first sealing region 3007, a material containing glass (e.g., a glass frit, a glass ribbon, and the like) can be used. For the second sealing region 3009, a material containing a resin can be used. With the use of the material containing glass for the first sealing region 3007, productivity and a sealing property can be improved. Moreover, with the use of the material containing a resin for the second sealing region 3009, impact resistance and heat resistance can be improved. However, the materials used for the first sealing region 3007 and the second sealing region 3009 are not limited to such, and the first sealing region 3007 may be formed using the material containing a resin and the second sealing region 3009 may be formed using the material containing glass.

The glass frit may contain, for example, magnesium oxide, calcium oxide, strontium oxide, barium oxide, cesium oxide, sodium oxide, potassium oxide, boron oxide, vanadium oxide, zinc oxide, tellurium oxide, aluminum oxide, silicon dioxide, lead oxide, tin oxide, phosphorus oxide, ruthenium oxide, rhodium oxide, iron oxide, copper oxide, manganese dioxide, molybdenum oxide, niobium oxide, titanium oxide, tungsten oxide, bismuth oxide, zirconium oxide, lithium oxide, antimony oxide, lead borate glass, tin phosphate glass, vanadate glass, or borosilicate glass. The glass frit preferably contains at least one kind of transition metal to absorb infrared light.

As the above glass frits, for example, a frit paste is applied to a substrate and is subjected to heat treatment, laser light irradiation, or the like. The frit paste contains the glass frit and a resin (also referred to as a binder) diluted by an organic solvent. Note that an absorber which absorbs light having the wavelength of laser light may be added to the glass frit. For example, an Nd:YAG laser or a semiconductor laser is preferably used as the laser. The shape of laser light may be circular or quadrangular.

As the above material containing a resin, for example, polyester, polyolefin, polyamide (e.g., nylon, aramid), polyimide, polycarbonate, or an acrylic resin, polyurethane, or an

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epoxy resin can be used. Alternatively, a material that includes a resin having a siloxane bond such as silicone can be used.

Note that in the case where the material containing glass is used for one or both of the first sealing region 3007 and the second sealing region 3009, the material containing glass preferably has a thermal expansion coefficient close to that of the substrate 3001. With the above structure, generation of a crack in the material containing glass or the substrate 3001 due to thermal stress can be suppressed.

For example, the following advantageous effect can be obtained in the case where the material containing glass is used for the first sealing region 3007 and the material containing a resin is used for the second sealing region 3009.

The second sealing region 3009 is provided closer to an outer portion of the light-emitting device 3000 than the first sealing region 3007 is. In the light-emitting device 3000, distortion due to external force or the like increases toward the outer portion. Thus, the outer portion of the light-emitting device 3000 where a larger amount of distortion is generated, that is, the second sealing region 3009 is sealed using the material containing a resin and the first sealing region 3007 provided on an inner side of the second sealing region 3009 is sealed using the material containing glass, whereby the light-emitting device 3000 is less likely to be damaged even when distortion due to external force or the like is generated.

Furthermore, as illustrated in FIG. 30B, a first region 3011 corresponds to the region surrounded by the substrate 3001, the substrate 3003, the first sealing region 3007, and the second sealing region 3009. A second region 3013 corresponds to the region surrounded by the substrate 3001, the substrate 3003, the light-emitting element 3005, and the first sealing region 3007.

The first region 3011 and the second region 3013 are preferably filled with, for example, an inert gas such as a rare gas or a nitrogen gas. Alternatively, the first region 3011 and the second region 3013 are preferably filled with a resin such as an acrylic resin or an epoxy resin. Note that for the first region 3011 and the second region 3013, a reduced pressure state is preferred to an atmospheric pressure state.

FIG. 30C illustrates a modification example of the structure in FIG. 30B. FIG. 30C is a cross-sectional view illustrating the modification example of the light-emitting device 3000.

FIG. 30C illustrates a structure in which a desiccant 3018 is provided in a recessed portion provided in part of the substrate 3003. The other components are the same as those of the structure illustrated in FIG. 30B.

As the desiccant 3018, a substance which adsorbs moisture and the like by chemical adsorption or a substance which adsorbs moisture and the like by physical adsorption can be used. Examples of the substance that can be used as the desiccant 3018 include alkali metal oxides, alkaline earth metal oxide (e.g., calcium oxide, barium oxide, and the like), sulfate, metal halides, perchlorate, zeolite, silica gel, and the like.

Next, modification examples of the light-emitting device 3000 which is illustrated in FIG. 30B are described with reference to FIGS. 31A to 31D. Note that FIGS. 31A to 31D are cross-sectional views illustrating the modification examples of the light-emitting device 3000 illustrated in FIG. 30B.

In each of the light-emitting devices illustrated in FIGS. 31A to 31D, the second sealing region 3009 is not provided but only the first sealing region 3007 is provided. Moreover, in each of the light-emitting devices illustrated in FIGS. 31A

to 31D, a region 3014 is provided instead of the second region 3013 illustrated in FIG. 30B.

For the region 3014, for example, polyester, polyolefin, polyamide (e.g., nylon, aramid), polyimide, polycarbonate, or an acrylic resin, polyurethane, or an epoxy resin can be used. Alternatively, a material that includes a resin having a siloxane bond such as silicone can be used.

When the above-described material is used for the region 3014, what is called a solid-sealing light-emitting device can be obtained.

In the light-emitting device illustrated in FIG. 31B, a substrate 3015 is provided on the substrate 3001 side of the light-emitting device illustrated in FIG. 31A.

The substrate 3015 has unevenness as illustrated in FIG. 31B. With a structure in which the substrate 3015 having unevenness is provided on the side through which light emitted from the light-emitting element 3005 is extracted, the efficiency of extraction of light from the light-emitting element 3005 can be improved. Note that instead of the structure having unevenness and illustrated in FIG. 31B, a substrate having a function as a diffusion plate may be provided.

In the light-emitting device illustrated in FIG. 31C, light is extracted through the substrate 3003 side, unlike in the light-emitting device illustrated in FIG. 31A, in which light is extracted through the substrate 3001 side.

The light-emitting device illustrated in FIG. 31C includes the substrate 3015 on the substrate 3003 side. The other components are the same as those of the light-emitting device illustrated in FIG. 31B.

In the light-emitting device illustrated in FIG. 31D, the substrate 3003 and the substrate 3015 included in the light-emitting device illustrated in FIG. 31C are not provided but a substrate 3016 is provided.

The substrate 3016 includes first unevenness positioned closer to the light-emitting element 3005 and second unevenness positioned farther from the light-emitting element 3005. With the structure illustrated in FIG. 31D, the efficiency of extraction of light from the light-emitting element 3005 can be further improved.

Thus, the use of the structure described in this embodiment can provide a light-emitting device in which deterioration of a light-emitting element due to impurities such as moisture and oxygen is suppressed. Alternatively, with the structure described in this embodiment, a light-emitting device having high light extraction efficiency can be obtained.

Note that the structure described in this embodiment can be combined as appropriate with any of the structures described in the other embodiments.

EMBODIMENT 9

In this embodiment, examples in which the light-emitting element of one embodiment of the present invention is used for various lighting devices and electronic devices will be described with reference to FIGS. 32A to 32C and FIG. 33.

An electronic device or a lighting device that has a light-emitting region with a curved surface can be obtained with the use of the light-emitting element of one embodiment of the present invention which is manufactured over a substrate having flexibility.

Furthermore, a light-emitting device to which one embodiment of the present invention is applied can also be used for lighting for motor vehicles, examples of which are lighting for a dashboard, a windshield, a ceiling, and the like.

FIG. 32A is a perspective view illustrating one surface of a multifunction terminal 3500, and FIG. 32B is a perspective view illustrating the other surface of the multifunction terminal 3500. In a housing 3502 of the multifunction terminal 3500, a display portion 3504, a camera 3506, lighting 3508, and the like are incorporated. The light-emitting device of one embodiment of the present invention can be used for the lighting 3508.

The lighting 3508 that includes the light-emitting device of one embodiment of the present invention functions as a planar light source. Thus, unlike a point light source typified by an LED, the lighting 3508 can provide light emission with low directivity. When the lighting 3508 and the camera 3506 are used in combination, for example, imaging can be performed by the camera 3506 with the lighting 3508 lighting or flashing. Because the lighting 3508 functions as a planar light source, a photograph as if taken under natural light can be taken.

Note that the multifunction terminal 3500 illustrated in FIGS. 32A and 32B can have a variety of functions as in the electronic devices illustrated in FIGS. 27A to 27G.

The housing 3502 can include a speaker, a sensor (a sensor having a function of measuring force, displacement, position, speed, acceleration, angular velocity, rotational frequency, distance, light, liquid, magnetism, temperature, chemical substance, sound, time, hardness, electric field, current, voltage, electric power, radiation, flow rate, humidity, gradient, oscillation, odor, or infrared rays), a microphone, and the like. When a detection device including a sensor for detecting inclination, such as a gyroscope or an acceleration sensor, is provided inside the multifunction terminal 3500, display on the screen of the display portion 3504 can be automatically switched by determining the orientation of the multifunction terminal 3500 (whether the multifunction terminal is placed horizontally or vertically for a landscape mode or a portrait mode).

The display portion 3504 may function as an image sensor. For example, an image of a palm print, a fingerprint, or the like is taken when the display portion 3504 is touched with the palm or the finger, whereby personal authentication can be performed. Furthermore, by providing a backlight or a sensing light source which emits near-infrared light in the display portion 3504, an image of a finger vein, a palm vein, or the like can be taken. Note that the light-emitting device of one embodiment of the present invention may be used for the display portion 3504.

FIG. 32C is a perspective view of a security light 3600. The security light 3600 includes lighting 3608 on the outside of the housing 3602, and a speaker 3610 and the like are incorporated in the housing 3602. The light-emitting device of one embodiment of the present invention can be used for the lighting 3608.

The security light 3600 emits light when the lighting 3608 is gripped or held, for example. An electronic circuit that can control the manner of light emission from the security light 3600 may be provided in the housing 3602. The electronic circuit may be a circuit that enables light emission once or intermittently a plurality of times or may be a circuit that can adjust the amount of emitted light by controlling the current value for light emission. A circuit with which a loud audible alarm is output from the speaker 3610 at the same time as light emission from the lighting 3608 may be incorporated.

The security light 3600 can emit light in various directions; therefore, it is possible to intimidate a thug or the like with light, or light and sound. Moreover, the security light 3600 may include a camera such as a digital still camera to have a photography function.

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FIG. 33 illustrates an example in which the light-emitting element is used for an indoor lighting device **8501**. Since the light-emitting element can have a larger area, a lighting device having a large area can also be formed. In addition, a lighting device **8502** in which a light-emitting region has a curved surface can also be formed with the use of a housing with a curved surface. A light-emitting element described in this embodiment is in the form of a thin film, which allows the housing to be designed more freely. Therefore, the lighting device can be elaborately designed in a variety of ways. Furthermore, a wall of the room may be provided with a large-sized lighting device **8503**. Touch sensors may be provided in the lighting devices **8501**, **8502**, and **8503** to control the power on/off of the lighting devices.

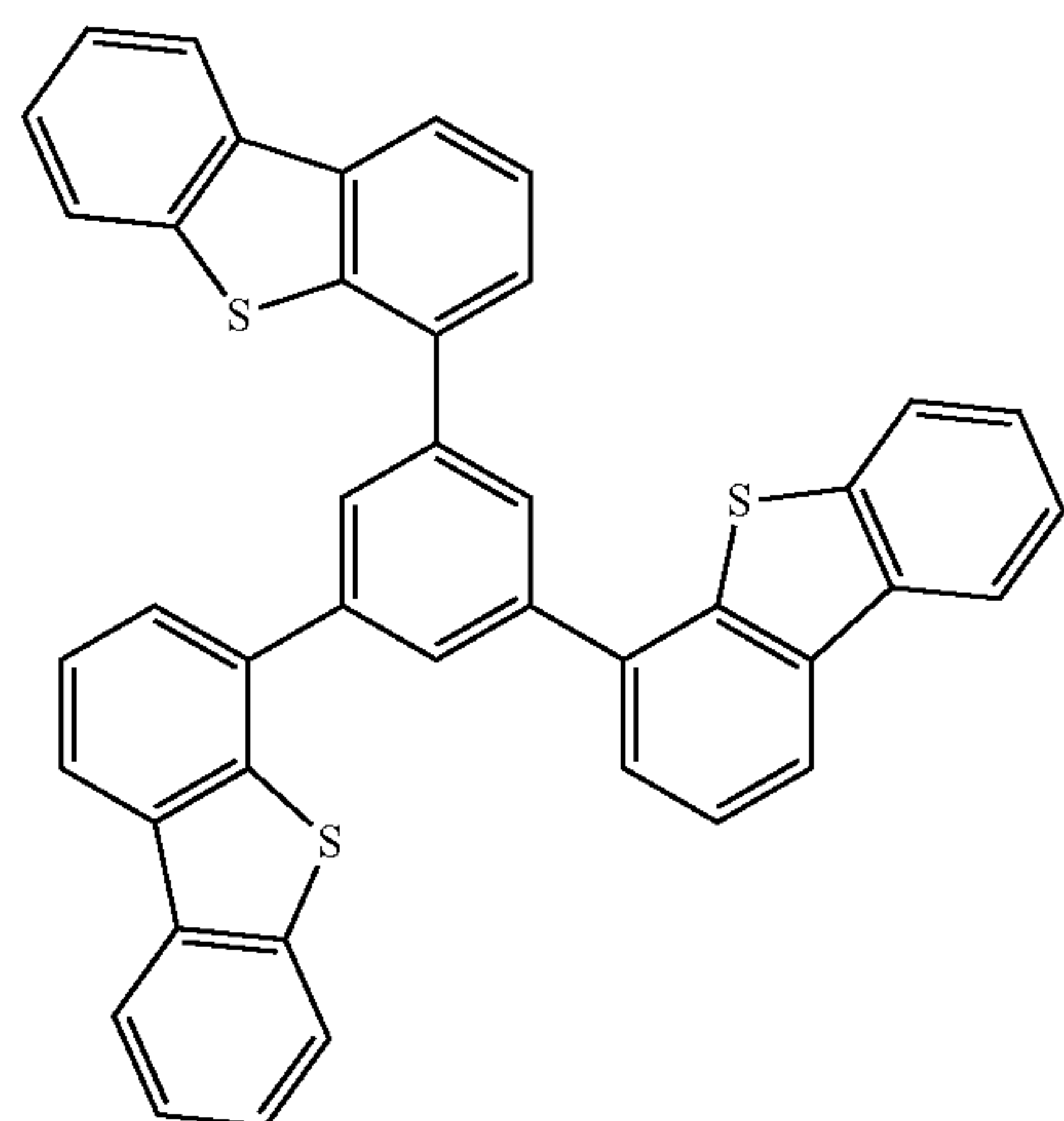
Moreover, when the light-emitting element is used on the surface side of a table, a lighting device **8504** which has a function as a table can be obtained. When the light-emitting element is used as part of other furniture, a lighting device which has a function as the furniture can be obtained.

As described above, lighting devices and electronic devices can be obtained by application of the light-emitting device of one embodiment of the present invention. Note that the light-emitting device can be used for lighting devices and electronic devices in a variety of fields without being limited to the lighting devices and the electronic devices described in this embodiment.

The structure described in this embodiment can be used in combination with any of the structures described in the other embodiments as appropriate.

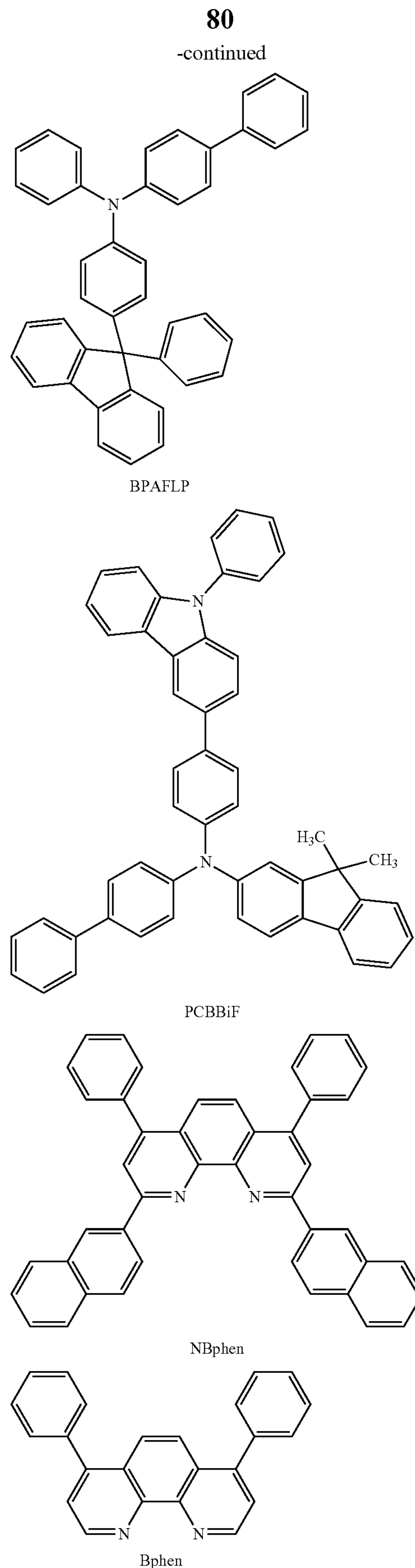
EXAMPLE 1

In this Example, an example of fabricating light-emitting elements of one embodiment of the present invention (a light-emitting element 1 and a light-emitting element 2) will be described. FIG. 34 is a schematic cross-sectional view of the light-emitting elements fabricated in this example. Table 1 shows details of the element structures. Structures and abbreviations of compounds used here are shown below.

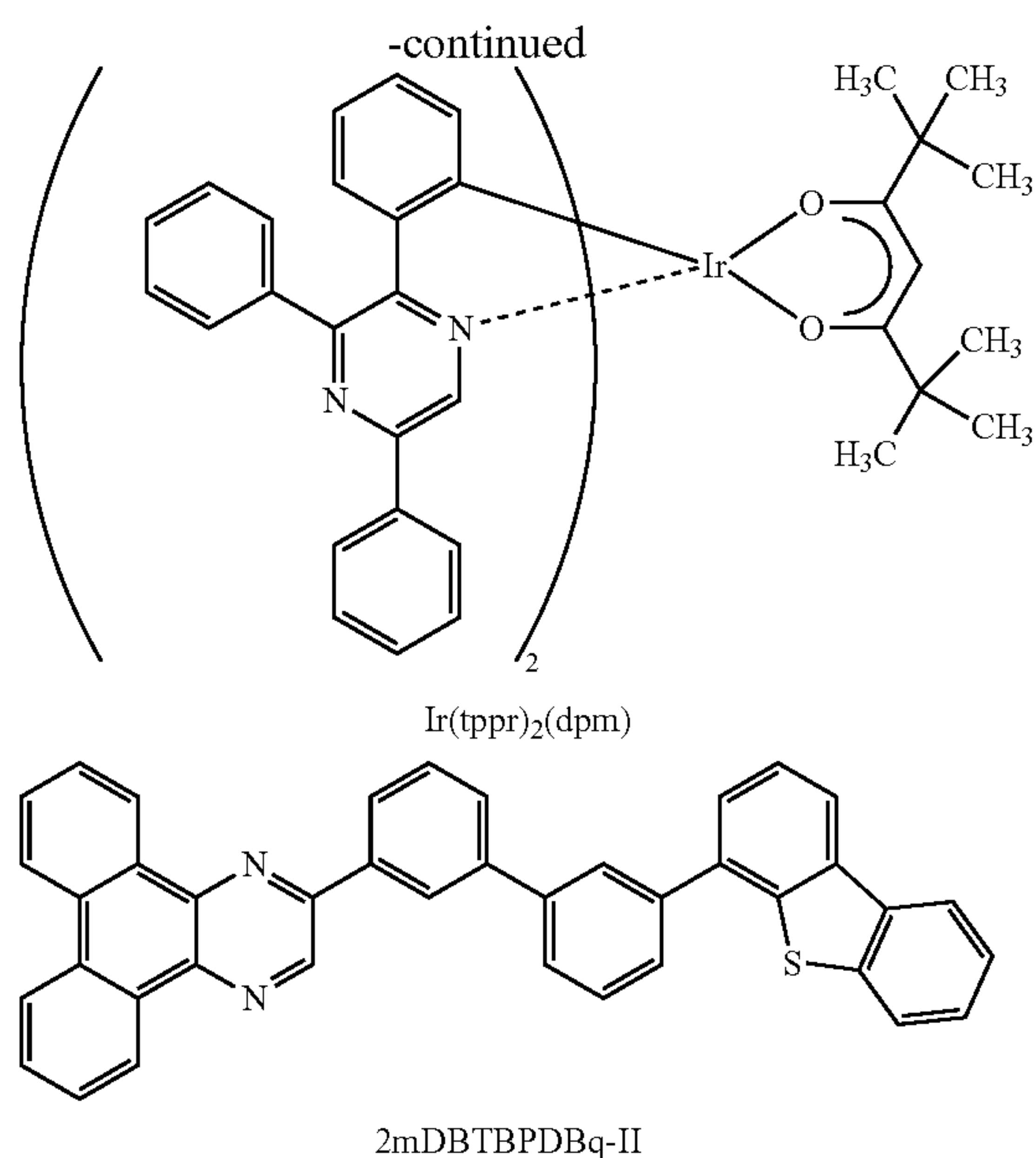


DBT3P-II

[Chemical Formulae 1]



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deposited by co-evaporation in a weight ratio of 2mDBTBPDBq-II:PCBBiF:Ir(tppr)₂(dpm)=0.7:0.3:0.05 to a thickness of 20 nm (as a layer **160(1)**), and successively, 2mDBTBPDBq-II, PCBBiF, and Ir(tppr)₂(dpm) were deposited by co-evaporation in a weight ratio of 2mDBTBPDBq-II:PCBBiF:Ir(tppr)₂(dpm)=0.8:0.2:0.05 to a thickness of 20 nm (as a layer **160(2)**). Note that in the light-emitting layer **160**, 2mDBTBPDBq-II corresponds to the first organic compound, PCBBiF corresponds to the second organic compound, and Ir(tppr)₂(dpm) corresponds to the guest material (the phosphorescent material).

As the electron-transport layer **118**, 2mDBTBPDBq-II (as a layer **118(1)**) and bathophenanthroline (abbreviation: BPhen, as a layer **118(2)**) were sequentially deposited by evaporation to thicknesses of 20 nm and 15 nm, respectively, over the light-emitting layer **160**. Then, as the electron-injection layer **119**, lithium fluoride (LiF) was deposited over the electron-transport layer **118** by evaporation to a thickness of 1 nm.

As the electrode **102**, aluminum (Al) was deposited over the electron-injection layer **119** to a thickness of 200 nm.

Next, in a glove box containing a nitrogen atmosphere, the light-emitting element **1** was sealed by fixing the substrate **220** to the substrate **200** over which the organic

TABLE 1

	Layer	Reference	Thickness (nm)	Material	Weight ratio
Light-emitting element 1	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	15	BPhen	—
		118(1)	20	2mDBTBPDBq-II	—
	Light-emitting layer	160(2)	20	2mDBTBPDBq-II:PCBBiF:Ir(tppr) ₂ (dpm)	0.8:0.2:0.05
		160(1)	20	2mDBTBPDBq-II:PCBBiF:Ir(tppr) ₂ (dpm)	0.7:0.3:0.05
	Hole-transport layer	112	20	BPAFLP	—
Light-emitting element 2	Hole-injection layer	111	60	DBT3P-II:MoO ₃	1:0.5
	Electrode	101	70	ITSO	—
	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	15	NBPhen	—
		118(1)	20	2mDBTBPDBq-II	—
	Light-emitting layer	160(2)	20	2mDBTBPDBq-II:PCBBiF:Ir(tppr) ₂ (dpm)	0.8:0.2:0.05
		160(1)	20	2mDBTBPDBq-II:PCBBiF:Ir(tppr) ₂ (dpm)	0.7:0.3:0.05
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	60	DBT3P-II:MoO ₃	1:0.5
	Electrode	101	70	ITSO	—

<Fabrication of Light-Emitting Elements>

<<Fabrication of Light-Emitting Element 1>>

As the electrode **101**, an ITSO film was formed to a thickness of 70 nm over the substrate **200**. The electrode area of the electrode **101** was set to 4 mm² (2 mm×2 mm).

As the hole-injection layer **111**, 4,4',4''-(benzene-1,3,5-triyltri(dibenzothiophene)) (abbreviation: DBT3P-II) and molybdenum oxide (MoO₃) were deposited over the electrode **101** by co-evaporation in a weight ratio of DBT3P-II:MoO₃=1:0.5 to a thickness of 60 nm.

As the hole-transport layer **112**, 4-phenyl-4'-(9-phenylfluoren-9-yl)triphenylamine (abbreviation: BPAFLP) was deposited over the hole-injection layer **111** by evaporation to a thickness of 20 nm.

Next, as the light-emitting layer **160** over the hole-transport layer **112**, 2-[3'-(dibenzothiophen-4-yl)biphenyl-3-yl]dibenzo[f,h]quinoxaline (abbreviation: 2mDBTBPDBq-II), N-(1,1'-biphenyl-4-yl)-N-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]-9,9-dimethyl-9H-fluoren-2-amine (abbreviation: PCBBiF), and bis(2,3,5-triphenylpyrazinato) (dipivaloyl-methanato)iridium(III) (abbreviation: Ir(tppr)₂(dpm)) were

material was deposited using a sealant for an organic EL device. Specifically, the sealant was applied on the substrate **220**, and the substrate **220** was bonded to the substrate **200** over which the organic material was deposited. Then, irradiation with ultraviolet light having a wavelength of 365 nm at 6 J/cm² was performed, and then, heat treatment at 80° C. for one hour was performed. Through the process, the light-emitting element **1** was obtained.

<<Fabrication of Light-Emitting Element 2>>

The light-emitting element **2** was fabricated in a manner similar to the light-emitting element **1** except a step of forming the electron-transport layer **118**, whose material was different from that in the light-emitting element **1**.

Specifically, as the electron-transport layer **118** of the light-emitting element **2**, 2mDBTBPDBq-II (as a layer **118(1)**) and 2,9-bis(naphthalen-2-yl)-4,7-diphenyl-1,10-phenanthroline (abbreviation: NBPhen, as a layer **118(2)**) were sequentially deposited by evaporation to thicknesses of 20 nm and 15 nm, respectively.

<Emission Spectra of Host Materials>

In the light-emitting elements, 2mDBTBPDBq-II and PCBBiF were used as host materials (the first organic

compound and the second organic compound). FIG. 35 shows measurement results of emission spectra of a thin film of 2mDBTBPDBq-II alone, a thin film of PCBBiF alone, and a mixed thin film of 2mDBTBPDBq-II and PCBBiF.

For the emission spectrum measurement, thin film samples were fainted over a quartz substrate by a vacuum evaporation method. The emission spectra were measured at room temperature (in an atmosphere kept at 23° C.) with a PL-EL measurement apparatus (produced by Hamamatsu Photonics K.K.). The thickness of each thin film was 50 nm. The mixing ratio of the two kinds of compounds (the first organic compound: the second organic compound) in the mixed thin film was 0.8:0.2.

As shown in FIG. 35, the emission spectrum of the mixed thin film of 2mDBTBPDBq-II and PCBBiF differs from the emission spectra of 2mDBTBPDBq-II alone and PCBBiF alone. As described later, the LUMO level of 2mDBTBPDBq-II is lower than the LUMO level of PCBBiF, and the HOMO level of PCBBiF is higher than the HOMO level of 2mDBTBPDBq-II. The mixed thin film of 2mDBTBPDBq-II and PCBBiF emits light having an energy equivalent to the energy difference between the LUMO level of 2mDBTBPDBq-II and the HOMO level of PCBBiF. In addition, the light emission from the mixed thin film has a longer wavelength (lower energy) than light emission from 2mDBTBPDBq-II alone and light emission from PCBBiF alone. It can thus be said that the light emission from the mixed thin film results from an exciplex formed by these compounds. That is, 2mDBTBPDBq-II and PCBBiF are organic compounds which form an exciplex in combination with each other. The use of 2mDBTBPDBq-II and PCBBiF as host materials can fabricate a light-emitting element utilizing ExtET.

<Absorption and Emission Spectra of Guest Material>

FIG. 36 shows the measurement results of the absorption spectrum and the emission spectrum of Ir(tppr)₂(dpm) that is a guest material of the light-emitting elements.

For the absorption spectrum measurement, a dichloromethane solution in which the guest material (Ir(tppr)₂(dpm)) was dissolved was prepared, and a quartz cell was used. The absorption spectrum was measured using an ultraviolet-visible spectrophotometer (V-550, produced by JASCO Corporation). Then, the absorption spectrum of quartz cell was subtracted from the measured absorption spectrum. Note that the emission spectra of the solution were measured with a PL-EL measurement apparatus (manufactured by Hamamatsu Photonics K.K.). Note that the measurement was performed at room temperature (in an atmosphere kept at 23° C.).

As shown in FIG. 36, an absorption band on the lowest energy side (the longest wavelength side) of the absorption spectrum of Ir(tppr)₂(dpm) is at around 580 nm. The absorption edge was calculated from data of the absorption spectrum, and transition energy was estimated on the assumption of direct transition, so that the following results were obtained: the absorption edge of Ir(tppr)₂(dpm) is at 596 nm and transition energy of Ir(tppr)₂(dpm) is 2.08 eV.

The results show that the absorption band on the lowest energy side (the longest wavelength side) of the absorption spectrum of Ir(tppr)₂(dpm) has a region overlapping with the emission of the exciplex formed by 2mDBTBPDBq-II and PCBBiF (the emission spectrum shown in FIG. 35). Therefore, in the light-emitting elements 1 and 2 each including 2mDBTBPDBq-II and PCBBiF as host materials, excitation energy can be effectively transferred to the guest material.

As described above, the light-emitting elements 1 and 2 are light-emitting elements in each of which an exciplex is

formed by the host materials of 2mDBTBPDBq-II (the first organic compound) and PCBBiF (the second organic compound) in combination.

<Phosphorescence Emission Spectra of Host Materials>

FIG. 37 shows the results of measuring triplet excitation energy levels of the first organic compound (2mDBTBPDBq-II) and the second organic compound (PCBBiF) which were used as host materials.

For the triplet excitation energy level measurement, phosphorescence from thin films of the compounds was measured. The measurement was performed by using a PL microscope, LabRAM HR-PL, produced by HORMA, Ltd., a He—Cd laser (325 nm) as excitation light, and a CCD detector at a measurement temperature of 10 K. The triplet excitation energy levels were calculated from a peak on the shortest wavelength side of the phosphorescent spectrum obtained by the measurement.

As shown in FIG. 37, peak wavelengths on the shortest wavelength sides of the phosphorescence emission spectra of the first organic compound (2mDBTBPDBq-II) and the second organic compound (PCBBiF) were 515 nm and 509 nm, respectively. Thus, the triplet excitation energy levels of the first organic compound and the second organic compound derived from the results were 2.41 eV and 2.44 eV, respectively.

The peak wavelengths on the shortest wavelength sides of the phosphorescence emission spectra of 2mDBTBPDBq-II and PCBBiF are shorter than the peak wavelength, which has been shown in FIG. 35, on the shortest wavelength side of the emission spectrum of the exciplex formed by 2mDBTBPDBq-II and PCBBiF. The exciplex is characterized by a small energy difference between the singlet excitation energy level and the triplet excitation energy level; accordingly, the triplet excitation energy level of the exciplex can be derived from the peak wavelength on the shortest wavelength side of the emission spectrum. Thus, the triplet excitation energy levels of the first organic compound (2mDBTBPDBq-II) and the second organic compound (PCBBiF) are higher than the triplet excitation energy level of the exciplex.

In addition, the triplet excitation energy levels of 2mDBTBPDBq-II and PCBBiF are higher than the transition energy of the guest material (Ir(tppr)₂(dpm)), 2.08 eV, which was derived from the absorption spectrum edge shown in FIG. 36.

Therefore, the first organic compound (2mDBTBPDBq-II) and the second organic compound (PCBBiF), the host materials in this example, have triplet excitation energy levels high enough for host materials.

<Characteristics of Light-Emitting Elements>

Next, the characteristics of the fabricated light-emitting elements 1 and 2 were measured. For measuring the luminance and the CIE chromaticity, a luminance colorimeter (BM-5A produced by Topcon Technohouse Corporation) was used. For measuring the electroluminescence spectrum, a multi-channel spectrometer (PMA-11 produced by Hamamatsu Photonics K.K.) was used.

FIGS. 38, 39, 40, and 41 respectively show luminance-current density characteristics, luminance-voltage characteristics, current efficiency-luminance characteristics, and external quantum efficiency-luminance characteristics of the light-emitting elements 1 and 2. FIG. 42 shows emission spectra when the current density in the light-emitting elements 1 and 2 was 2.5 mA/cm². FIG. 45 shows measurement results of angle distribution of light from the light-emitting

elements 1 and 2. The measurement of the light-emitting element was performed at room temperature (in an atmosphere kept at 23° C.).

Table 2 shows the characteristics of the light-emitting elements 1 and 2 at around 1000 cd/m².

TABLE 2

	Voltage (V)	Current density (mA/cm ²)	CIE chromaticity (x, y)	Luminance (cd/m ²)	Current efficiency (cd/A)	Power efficiency (lm/W)	External quantum efficiency (%)
Light-emitting element 1	3.20	3.14	(0.665, 0.335)	996	31.7	31.1	22.2
Light-emitting element 2	3.20	2.86	(0.662, 0.338)	978	34.2	33.6	21.5

As shown in FIG. 42, the electroluminescence spectra of red light from the light-emitting elements 1 and 2 have peak wavelengths at 620 nm and 616 nm, respectively, and full widths at half maximum of 73 nm and 69 nm, respectively.

The results of measuring angular distributions of light emission of the light-emitting elements 1 and 2 are shown in FIG. 45, and their differences from a perfectly diffusing surface (also referred to as a Lambertian surface) were 89.3% and 85.5%, respectively. Note that the difference is also referred to as Lambertian ratio. The external quantum efficiencies shown in Table 2 are each the product of the external quantum efficiency that was calculated from front luminance under assumption of Lambertian distribution and the Lambertian ratio for estimating true external quantum efficiency in consideration of luminous flux in every direction. Note that FIG. 41 shows both the external quantum efficiency calculated from luminance measured from the front under assumption of Lambertian distribution and the true one.

As shown in FIGS. 40 and 41 and Table 2, the light-emitting elements 1 and 2 showed high current efficiency while exhibiting deep red with chromaticities x of 0.665 and 0.662, respectively. In addition, the maximum values of the external quantum efficiencies (true values) of the light-emitting elements 1 and 2 were excellent, 23.1% and 22.4%, respectively. As shown in FIG. 39, the light-emitting elements 1 and 2 were driven at lower driving voltages; thus, the light-emitting elements 1 and 2 showed excellent power efficiency.

The light emission starting voltages (a voltage at the time when the luminance exceeds 1 cd/m²) of the light-emitting elements 1 and 2 were each 2.3 V. This voltage is smaller than a voltage corresponding to an energy difference between the LUMO level and the HOMO level of the guest material Ir(tppr)₂(dpm), which is described later. The results suggest that emission in the light-emitting elements 1 and 2 is obtained not by direct recombination of carriers in the guest material but by recombination of carriers in the material having a smaller energy gap.

<Results of CV Measurement>

The electrochemical characteristics (oxidation reaction characteristics and reduction reaction characteristics) of the compounds used as the host materials (the first organic compound and the second organic compound) and the guest material in the above-described light-emitting elements were examined by cyclic voltammetry (CV). Note that for the measurement, an electrochemical analyzer (ALS model 600A or 600C, produced by BAS Inc.) was used, and measurement was performed on a solution obtained by dissolving each compound in N,N-dimethylformamide (ab-

breviation: DMF). In the measurement, the potential of a working electrode with respect to the reference electrode was changed within an appropriate range, so that the oxidation peak potential and the reduction peak potential were obtained. In addition, the HOMO and LUMO levels of each

compound were calculated from the estimated redox potential of the reference electrode of 4.94 eV and the obtained peak potentials.

Table 3 shows oxidation potentials and reduction potentials obtained by CV measurement and HOMO levels and LUMO levels of the compounds calculated from the CV measurement results.

TABLE 3

Abbreviation	Oxidation potential (V)	Reduction potential (V)	HOMO level calculated from oxidation potential (eV)	LUMO level calculated from reduction potential (eV)
2mDBTBPDBq-II	1.28	-2.00	-6.22	-2.94
PCBBiF	0.42	-2.94	-5.36	-2.00
Ir(tppr) ₂ (dpm)	0.63	-1.90	-5.57	-3.05

FIG. 44 shows the work functions of a pair of electrodes (ITSO and Al) and the LUMO and HOMO levels of the compounds contained in the light-emitting elements 1 and 2. The LUMO and HOMO levels were estimated by the CV measurement. The work functions of the pair of electrodes were measured by photoelectron spectrometer (AC-2 produced by Riken Keiki Co., Ltd.) in the air.

As shown in Table 3, the reduction potential of the first organic compound (2mDBTBPDBq-II) is higher than that of the second organic compound (PCBBiF), the oxidation potential of the first organic compound (2mDBTBPDBq-II) is higher than that of the second organic compound (PCBBiF), the reduction potential of the guest material (Ir(tppr)₂(dpm)) is higher than that of the first organic compound (2mDBTBPDBq-II), and the oxidation potential of the guest material (Ir(tppr)₂(dpm)) is higher than that of the second organic compound (PCBBiF). Therefore, the LUMO level of the first organic compound (2mDBTBPDBq-II) is lower than that of the second organic compound (PCBBiF), the HOMO level of the first organic compound (2mDBTBPDBq-II) is lower than that of the second organic compound (PCBBiF), the LUMO level of the guest material (Ir(tppr)₂(dpm)) is lower than that of the first organic compound (2mDBTBPDBq-II), and the HOMO level of the guest material (Ir(tppr)₂(dpm)) is higher than that of the second organic compound (PCBBiF).

The CV measurement results show that the combination of the first organic compound (2mDBTBPDBq-II) and the second organic compound (PCBBiF) forms an exciplex.

Note that an energy difference between the LUMO level and the HOMO level of Ir(tppr)₂(dpm) was calculated to be 2.52 eV from the CV measurement results shown in Table 3.

As described above, the transition energy of $\text{Ir}(\text{tppr})_2(\text{dpm})$ (dpm) obtained from the absorption spectrum edge in FIG. 36 was 2.08 eV.

Thus, in $\text{Ir}(\text{tppr})_2(\text{dpm})$, the energy difference between the LUMO level and the HOMO level was larger than the transition energy calculated from the absorption edge by 0.44 eV.

The light emission energy of $\text{Ir}(\text{tppr})_2(\text{dpm})$ was determined as 1.98 eV because the peak wavelength on the shortest wavelength side of the light emission spectrum in FIG. 36 was 625 nm.

Thus, in $\text{Ir}(\text{tppr})_2(\text{dpm})$, the energy difference between the LUMO level and the HOMO level was larger than the light emission energy by 0.54 eV.

Consequently, in each of the guest materials of the light-emitting elements, the energy difference between the LUMO level and the HOMO level is larger than the transition energy calculated from the absorption edge by 0.4 eV or more. In addition, the energy difference between the LUMO level and the HOMO level is larger than the light emission energy by 0.4 eV or more. Therefore, high energy corresponding to the energy difference between the LUMO level and the HOMO level is needed, that is, high voltage is needed when carriers injected from a pair of electrodes are directly recombined in the guest material.

However, in the light-emitting element of one embodiment of the present invention, the guest material can be excited by energy transfer from an exciplex without the direct carrier recombination in the guest material, whereby the driving voltage can be lowered. Therefore, the light-emitting element of one embodiment of the present invention enables reduction in power consumption.

Note that an energy difference between the LUMO level of the first organic compound (2mDBTBPDQ-II) and the HOMO level of the second organic compound (PCBBiF) was calculated to be 2.42 eV from Table 3. Consequently, energy corresponding to the energy difference between the LUMO level and the HOMO level of an exciplex formed by the host materials is smaller than the energy difference between the LUMO level and the HOMO level (2.52 eV) of the guest material, and larger than the transition energy (2.08 eV) calculated from the absorption edge of the guest material. Therefore, in the light-emitting elements 1 and 2, the guest material can be excited through the exciplex, whereby the driving voltage can be lowered. Therefore, the light-emitting element of one embodiment of the present invention enables reduction in power consumption.

According to the CV measurement results in Table 3, among carriers (electrons and holes) injected from the pair of electrodes, holes tend to be injected into the second organic compound (PCBBiF) which is a host material with a high HOMO level, whereas electrons tend to be injected into the guest material ($\text{Ir}(\text{tppr})_2(\text{dpm})$) with a low LUMO level. That is, it seems at a glance that there is a possibility that an exciplex is formed by the second organic compound (PCBBiF) and the guest material ($\text{Ir}(\text{tppr})_2(\text{dpm})$).

However, an exciplex is not formed by the second organic compound and the guest material. This is shown by the fact that the full widths at half maximum of the electroluminescence spectra of the light-emitting elements 1 and 2 (73 nm and 69 nm, respectively) in FIG. 42 are near that of the emission spectrum of $\text{Ir}(\text{tppr})_2(\text{dpm})$ (89 nm) in FIG. 36. In addition, the peak wavelengths of the electroluminescence spectra and the emission spectrum are close to each other. The present inventors found this characteristic phenomenon.

An energy difference between the HOMO level of the second organic compound (PCBBiF) and the LUMO level

of the guest material ($\text{Ir}(\text{tppr})_2(\text{dpm})$) was calculated to be 2.31 eV from the CV measurement results in Table 3.

Thus, in the light-emitting elements 1 and 2 each containing $\text{Ir}(\text{tppr})_2(\text{dpm})$, the energy difference (2.31 eV) between the HOMO level of the second organic compound (PCBBiF) and the LUMO level of the guest material ($\text{Ir}(\text{tppr})_2(\text{dpm})$) is larger than or equal to the transition energy (2.08 eV) calculated from the absorption spectrum edge of the guest material ($\text{Ir}(\text{tppr})_2(\text{dpm})$). In addition, the energy difference (2.31 eV) between the HOMO level of the second organic compound (PCBBiF) and the LUMO level of the guest material ($\text{Ir}(\text{tppr})_2(\text{dpm})$) is larger than or equal to the light emission energy (1.96 eV) of the guest material ($\text{Ir}(\text{tppr})_2(\text{dpm})$). Accordingly, transfer of excitation energy to the guest material is more facilitated eventually rather than formation of an exciplex by the combination of the second organic compound and the guest material, so that light emission from the guest material is efficiently obtained. This relationship is a feature of one embodiment of the present invention for efficient light emission.

<Results of Reliability Test>

Next, results of reliability tests of the light-emitting elements 1 and 2 are shown in FIG. 43. Note that for the reliability tests, the current density and the initial luminance of the light-emitting element 1 were set to 17 mA/cm² and 5000 cd/m², respectively, and those of the light-emitting element 2 were set to 25 mA/cm² and 7600 cd/m², respectively. The light-emitting elements kept being driven with the respective current densities maintained.

The time (LT90) taken for the luminance of the light-emitting elements 1 and 2 to decrease to 90% of the initial luminance was as follows: the light-emitting element 1, 610 hours; and the light-emitting element 2, 290 hours, which shows high reliability.

The initial luminance of the light-emitting element 2 is 1.52 times as high as that of the light-emitting element 1. The LT90 of the light-emitting element 2 is 1/2.1 times as long as that of the light-emitting element 1. The luminance acceleration factor of the light-emitting elements fabricated in this example is 1.7, and the luminance decay time thereof is $1.5^{-1.7}$ (=0.50) with the 1.5 times initial luminance. That is, the luminance decay time is reduced in half with the 1.5-times initial luminance. The results show that the reliabilities of the light-emitting elements 1 and 2 are excellent and almost equivalent to each other.

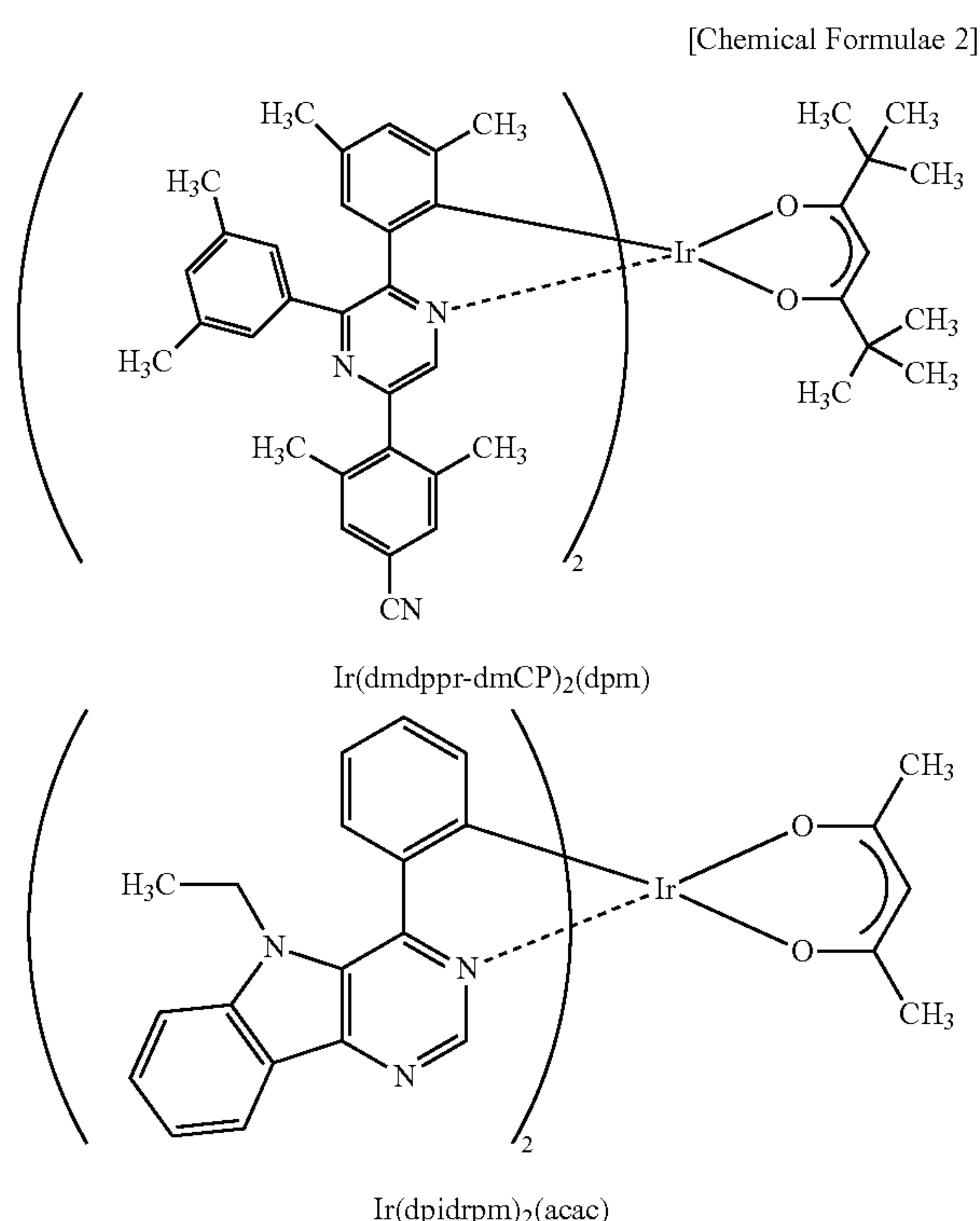
A light-emitting element having the following structure like the light-emitting elements 1 and 2 can achieve high emission efficiency with low driving voltage and have excellent reliability: the LUMO level of the first organic compound is lower than that of the second organic compound, the HOMO level of the first organic compound is lower than that of the second organic compound, the LUMO level of the guest material is lower than that of the first organic compound, and the HOMO level of the guest material is lower than that of the second organic compound, the first organic compound and the second organic compound form an exciplex in combination with each other, and the energy difference between the HOMO level of the second organic compound and the LUMO level of the guest material is larger than or equal to the transition energy calculated from the absorption edge of the guest material or is larger than or equal to the light emission energy of the guest material.

As described above, by employing the structure of one embodiment of the present invention, a light-emitting element having high emission efficiency can be fabricated. Furthermore, a light-emitting element with reduced power

consumption can be fabricated. A highly reliable light-emitting element can be fabricated.

EXAMPLE 2

In this example, examples of fabricating light-emitting elements (light-emitting elements 3 and 4) of one embodiment of the present invention are described. A schematic cross-sectional view of the light-emitting elements fabricated in this example is similar to FIG. 34 in this example. The detailed element structures are shown in Table 4. In addition, structures and abbreviations of compounds used here are given below. Note that Example 1 can be referred to for structures and abbreviations of other compounds.



<Fabrication of Light-Emitting Element>

<<Fabrication of Light-Emitting Element 3>>

As the electrode **101**, an ITSO film was formed to a thickness of 110 nm over the substrate **200**. The electrode area of the electrode **101** was set to 4 mm² (2 mm×2 mm).

As the hole-injection layer **111**, 4,4',4''-(benzene-1,3,5-triyl)tri(dibenzothiophene) (abbreviation: DBT3P-II) and molybdenum oxide (MoO₃) were deposited over the electrode **101** by co-evaporation in a weight ratio of DBT3P-II:MoO₃=1:0.5 to a thickness of 20 nm.

Next, as the hole-transport layer **112**, BPAFLP was deposited over the hole-injection layer **111** by evaporation to a thickness of 20 nm.

As the light-emitting layer **160** over the hole-transport layer **112**, 2mDBTBPDBq-II, PCBBiF, bis[2-(5-ethyl-5H-pyrimido[5,4-b]indol-4-yl-κN3)phenyl-κC](2,4-pentanedionato-κ²O,O')iridium(III) (abbreviation: Ir(pidrpm)₂(acac)) were deposited by co-evaporation with a weight ratio of 2mDBTBPDBq-II:PCBBiF:Ir(pidrpm)₂(acac)=0.8:0.2:0.01 and to a thickness of 40 nm. Note that in the light-emitting layer **160**, 2mDBTBPDBq-II is the first organic compound, PCBBiF is the second organic compound, and Ir(pidrpm)₂(acac) is the guest material (the phosphorescent material).

Next, as the electron-transport layer **118**, 2mDBTBPDBq-II (as a layer **118(1)**) and BPhen (as a layer **118(2)**) were sequentially deposited by evaporation to thicknesses of 20 nm and 10 nm, respectively, over the light-emitting layer **160**. Then, as the electron-injection layer **119**, lithium fluoride (LiF) was deposited over the electron-transport layer **118** by evaporation to a thickness of 1 nm.

As the electrode **102**, aluminum (Al) was deposited over the electron-injection layer **119** to a thickness of 200 nm.

Next, in a glove box containing a nitrogen atmosphere, the light-emitting element 3 was sealed by fixing the substrate **220** to the substrate **200** over which the organic material was deposited using a sealant for an organic EL device. Example 1 is referred to for the detailed process. Finally, the light-emitting element 3 was obtained.

<<Fabrication of Light-Emitting Element 4>>

The light-emitting element 4 was fabricated through the same steps as those for the light-emitting element 1 in Example 1 except for the steps of forming the light-emitting layer **160** and the electron-transport layer **118**.

As the light-emitting layer **160** of the light-emitting element 4, 2mDBTBPDBq-II, PCBBiF, and bis{4,6-dim-

TABLE 4

	Layer	Reference	Thickness (nm)	Material	Weight ratio
Light-emitting element 3	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	10	BPhen	—
		118(1)	20	2mDBTBPDBq-II	—
	Light-emitting layer	160	40	2mDBTBPDBq-II:PCBBiF:Ir(pidrpm) ₂ (acac)	0.8:0.2:0.01
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	20	DBT3P-II:MoO ₃	1:0.5
Light-emitting element 4	Electrode	101	110	ITSO	—
	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	10	BPhen	—
		118(1)	20	2mDBTBPDBq-II	—
	Light-emitting layer	160(2)	20	2mDBTBPDBq-II:PCBBiF:Ir(dmdppr-dmCP) ₂ (dpm)	0.8:0.2:0.05
		160(1)	20	2mDBTBPDBq-II:PCBBiF:Ir(dmdppr-dmCP) ₂ (dpm)	0.7:0.3:0.05
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	60	DBT3P-II:MoO ₃	1:0.5
	Electrode	101	70	ITSO	—

ethyl-2-[5-(4-cyano-2,6-dimethylphenyl)-3-(3,5-dimethylphenyl)-2-pyrazinyl- κ N]phenyl- κ C}(2,2,6,6-tetramethyl-3,5-heptanedionato- κ^2 O,O')iridium(III) (abbreviation: Ir(dmdppr-dmCP)₂(dpm)) were deposited by co-evaporation in a weight ratio of 2mDBTBPDBq-II:PCBBiF:Ir(dmdppr-dmCP)₂(dpm)=0.7:0.3:0.05 to a thickness of 20 nm, and successively, 2mDBTBPDBq-II, PCBBiF, and Ir(dmdppr-dmCP)₂(dpm) were deposited by co-evaporation in a weight ratio of 2mDBTBPDBq-II:PCBBiF:Ir(dmdppr-dmCP)₂(dpm)=0.8:0.2:0.05 to a thickness of 20 nm. Note that in the light-emitting layer 160, 2mDBTBPDBq-II corresponds to the first organic compound, PCBBiF corresponds to the second organic compound, and Ir(dmdppr-dmCP)₂(dpm) corresponds to the guest material (the phosphorescent material). As the electron-transport layer 118, 2mDBTBPDBq-II and BPhen were sequentially deposited by evaporation to thicknesses of 20 nm and 10 nm, respectively, over the light-emitting layer 160.

<Characteristics of Light-Emitting Elements>

Next, the characteristics of the light-emitting elements 3 and 4 were measured by a method similar to that in Example 1.

FIGS. 46, 47, 48, and 49 show luminance-current density characteristics, luminance-voltage characteristics, current efficiency-luminance characteristics, and external quantum efficiency-luminance characteristics, respectively, of the light-emitting elements 3 and 4. FIG. 50 shows the electroluminescence spectra of the light-emitting elements 3 and 4 through which current flows at a current density of 2.5 mA/cm². The measurements of the light-emitting elements were performed at room temperature (in an atmosphere kept at 23° C.). The external quantum efficiency in this example was calculated by measuring luminance from the front on the assumption of light distribution on a perfectly diffusing surface (also referred to as Lambertian surface).

Table 5 shows element characteristics of the light-emitting elements 3 and 4 at around 1000 cd/m².

TABLE 5

	Voltage (V)	Current density (mA/cm ²)	CIE chromaticity (x, y)	Luminance (cd/m ²)	Current efficiency (cd/A)	Power efficiency (lm/W)	External quantum efficiency (%)
Light-emitting element 3	3.10	1.70	(0.604, 0.394)	990	58.3	59.1	27.3
Light-emitting element 4	3.50	5.08	(0.691, 0.309)	1000	19.7	17.7	23.9

As shown in FIG. 50, the electroluminescence spectra of red light from the light-emitting elements 3 and 4 have peak wavelengths at 596 nm and 632 nm, respectively, and full widths at half maximum of 66 nm and 56 nm, respectively.

As shown in FIGS. 46 to 49 and Table 5, the light-emitting element 3 has higher current efficiency and higher external quantum efficiency. The light-emitting element 4 also has a high current efficiency and a high external quantum efficiency while showing deep red with chromaticity x of 0.691.

As shown in FIG. 47, the light emission starting voltages (a voltage at the time when the luminance exceeds 1 cd/m²) of the light-emitting elements 3 and 4 were each 2.3 V. This voltage is smaller than a voltage corresponding to an energy difference between the LUMO level and the HOMO level of the guest material, which is described later. The results suggest that emission in the light-emitting elements 3 and 4 are obtained not by direct recombination of carriers in the guest material but by recombination of carriers in the material having a smaller energy gap.

<Absorption Spectrum and Emission Spectrum of Guest Material>

FIG. 51 shows the measurement results of the absorption spectrum and the emission spectrum of Ir(pidrpm)₂(acac) which is the guest material of the light-emitting element 3. FIG. 52 shows the measurement results of the absorption spectrum and the emission spectrum of Ir(dmdppr-dmCP)₂(dpm) which is the guest material of the light-emitting element 4. Note that the measurement method was similar to that used in Example 1.

As shown in FIG. 51 and FIG. 52, the absorption bands on the lowest energy side (on the longest wavelength side) of the absorption spectra of Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm) are observed at around 550 nm and 590 nm, respectively. In addition, the absorption edges were obtained from data on the absorption spectra and transition energies were estimated on the assumption of direct transfer. According to the calculation, the absorption edge of Ir(pidrpm)₂(acac) and transition energy were 587 nm and 2.11 eV, respectively; and the absorption edge of Ir(dmdppr-dmCP)₂(dpm) and the transition energy thereof were 624 nm and 1.99 eV, respectively.

As shown in FIG. 35 in Example 1, 2mDBTBPDBq-II and PCBBiF are organic compounds which form an exciplex in combination with each other. The exciplex exhibits a broad emission spectrum from 430 nm to 650 nm.

The absorption bands on the lowest energy side (the longest wavelength side) of the absorption spectra of Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm) each include a region overlapping with emission (the emission spectrum of FIG. 35) of an exciplex formed by 2mDBTBPDBq-II and PCBBiF. Therefore, in the light-emitting elements 3 and 4 each including 2mDBTBPDBq-II and PCBBiF as host materials, excitation energy can be effectively transferred to the guest materials.

As shown in Example 1, T1 levels of 2mDBTBPDBq-II and PCBBiF are 2.41 eV and 2.44 eV, respectively, which

are higher than the transition energy calculated from the absorption spectrum edge of the guest material Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm).

Therefore, the first organic compound (2mDBTBPDBq-II) and the second organic compound (PCBBiF) which were used as host materials in this example have triplet excitation energy levels high enough for host materials.

<Results of CV Measurement>

The electrochemical characteristics (oxidation reaction characteristics and reduction reaction characteristics) of the guest materials Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm) of the light-emitting elements 3 and 4 were examined by cyclic voltammetry (CV). The measurement method was similar to that used in Example 1.

Table 6 shows oxidation potentials and reduction potentials obtained by CV measurement and HOMO levels and LUMO levels of the compounds calculated from the CV

measurement results. Note that Table 3 in Example 1 can be referred to for the measurement results of 2mDBTBPDq-II and PCBBiF.

TABLE 6

Abbreviation	Oxidation potential (V)	Reduction potential (V)	HOMO level calculated from oxidation potential (eV)	LUMO level calculated from reduction potential (eV)
Ir(pidrpm) ₂ (acac)	0.58	-1.92	-5.52	-3.03
Ir(dmdppr-dmCP) ₂ (dpm)	0.58	-1.95	-5.52	-3.00

As shown in Tables 3 and 6, the LUMO level of the first organic compound (2mDBTBPDq-II) is lower than that of the second organic compound (PCBBiF), the HOMO level of the first organic compound (2mDBTBPDq-II) is lower than that of the second organic compound (PCBBiF), the LUMO levels of the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)) are lower than the LUMO level of the first organic compound (2mDBTBPDq-II), and the HOMO levels of the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)) are lower than the HOMO level of the second organic compound (PCBBiF).

The CV measurement results show that the combination of the first organic compound (2mDBTBPDq-II) and the second organic compound (PCBBiF) forms an exciplex.

Note that an energy difference between the LUMO level and the HOMO level of Ir(pidrpm)₂(acac) was calculated to be 2.50 eV and that of Ir(dmdppr-dmCP)₂(dpm) was calculated to be 2.52 eV from the CV measurement results shown in Table 6.

As described above, the transition energies of Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm) obtained from the absorption spectrum edge in FIGS. 51 and 52 were 2.11 eV and 1.99 eV, respectively.

Thus, the energy difference between the LUMO level and the HOMO level was larger than the transition energy calculated from the absorption edge by 0.39 eV in Ir(pidrpm)₂(acac) and by 0.53 eV in Ir(dmdppr-dmCP)₂(dpm).

The light emission energies of Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm) were calculated to be 2.03 eV and 1.95 eV because the peak wavelengths on the shortest wavelength sides of the light emission spectra in FIGS. 51 and 52 were 610 nm and 635 nm.

Thus, the energy difference between the LUMO level and the HOMO level was larger than the light emission energy by 0.47 eV in Ir(pidrpm)₂(acac) and by 0.57 eV in Ir(dmdppr-dmCP)₂(dpm).

Consequently, in each of the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)) of the light-emitting elements 3 and 4, the energy difference between the LUMO level and the HOMO level is larger than the transition energy calculated from the absorption edge by 0.3 eV or more. The energy difference between the LUMO level and the HOMO level is larger than the light emission energy by 0.4 eV or more. Therefore, high energy corresponding to the energy difference between the LUMO level and the HOMO level is needed, that is, high voltage is needed when carriers injected from a pair of electrodes are directly recombined in the guest material.

However, in the light-emitting element of one embodiment of the present invention, the guest material can be

excited by energy transfer from an exciplex without the direct carrier recombination in the guest material, whereby the driving voltage can be lowered. Therefore, the light-emitting element of one embodiment of the present invention enables reduction in power consumption.

Note that an energy difference between the LUMO level of the first organic compound (2mDBTBPDq-II) and the HOMO level of the second organic compound (PCBBiF) was calculated to be 2.42 eV from Table 3. Consequently, energy corresponding to the energy difference between the LUMO level and the HOMO level of an exciplex formed by the host materials is smaller than the energy difference between the LUMO level and the HOMO level of the guest materials (Ir(pidrpm)₂(acac), 2.50 eV; Ir(dmdppr-dmCP)₂(dpm), 2.52 eV), but larger than the transition energies calculated from the absorption edges of the guest materials (Ir(pidrpm)₂(acac), 2.11 eV; Ir(dmdppr-dmCP)₂(dpm), 1.99 eV). Therefore, in the light-emitting elements 3 and 4, the guest material can be excited through the exciplex, whereby the driving voltage can be lowered. The light-emitting element of one embodiment of the present invention enables reduction in power consumption.

According to the CV measurement results in Tables 3 and 6, among carriers (electrons and holes) injected from the pair of electrodes, holes tend to be injected into the second organic compound (PCBBiF) which is a host material with a high HOMO level, whereas electrons tend to be injected into the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)) with a low LUMO level. That is, it seems at a glance that there is a possibility that an exciplex is formed by the second organic compound (PCBBiF) and the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)).

However, an exciplex is not formed by the second organic compound and the guest materials. This is shown by the fact that the electroluminescence spectra of the light-emitting elements 3 and 4 are close to those of the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)) shown in FIGS. 51 and 52. The present inventors found this characteristic phenomenon.

An energy difference between the HOMO level of the second organic compound (PCBBiF) and the LUMO level of the guest material (Ir(pidrpm)₂(acac)) and an energy difference between the HOMO level of the second organic compound (PCBBiF) and the LUMO level of the guest material (Ir(dmdppr-dmCP)₂(dpm)) were calculated to be 2.33 eV and 2.36 eV, respectively, from the CV measurement results in Tables 3 and 6.

In addition, the energy differences (2.33 eV and 2.36 eV) between the HOMO level of the second organic compound (PCBBiF) and the LUMO levels of the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)) are larger than or equal to the transition energies (2.11 eV and 1.99 eV) calculated from the absorption edges of the absorption spectra of the guest materials. The energy differences (2.33 eV and 2.36 eV) between the HOMO level of the second organic compound (PCBBiF) and the LUMO levels of the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)) are larger than or equal to the light emission energies (2.03 eV and 1.95 eV) of the guest materials (Ir(pidrpm)₂(acac) and Ir(dmdppr-dmCP)₂(dpm)). Accordingly, transfer of excitation energy to the guest material is more facilitated eventually rather than formation of an exciplex by the combination of the second organic compound and the guest material, so that light emission from the guest material is efficiently obtained. This relationship is a feature of one embodiment of the present invention for efficient light emission.

<Results of Reliability Test>
Next, results of reliability tests of the light-emitting elements 3 and 4 are shown in FIG. 53. Note that for the reliability tests, the current density and the initial luminance of the light-emitting element 3 were set to 8.9 mA/cm² and 5000 cd/m², respectively, and those of the light-emitting element 4 were set to 50 mA/cm² and 8000 cd/m², respectively. The light-emitting elements kept being driven with the respective current densities maintained.

The time (LT90) taken for the luminance of the light-emitting elements 3 and 4 to decrease to 90% of the initial luminance was as follows: the light-emitting element 3, 140 hours; and the light-emitting element 4, 130 hours, which shows high reliability.

A light-emitting element having the following structure like the light-emitting elements 3 and 4 can achieve high

[Chemical Formula 3]

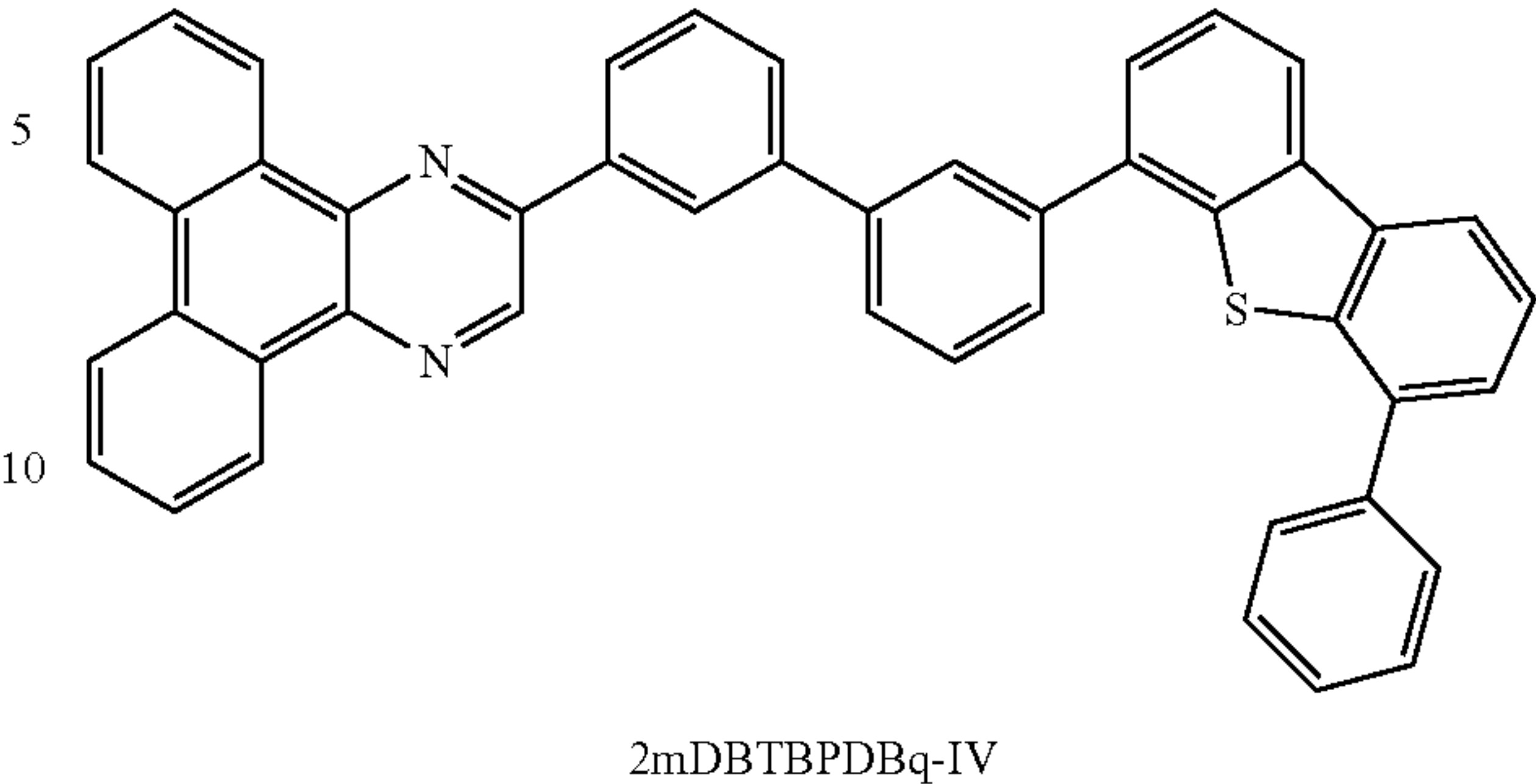


TABLE 7

Layer		Reference	Thickness (nm)	Material	Weight ratio
Light-emitting element 5	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	15	NBPhen	—
		118(1)	30	2mDBTBPDBq-IV	—
	Light-emitting layer	160(2)	20	2mDBTBPDBq-IV:PCBBiF:Ir(tppr) ₂ (dpm)	0.8:0.2:0.05
		160(1)	20	2mDBTBPDBq-IV:PCBBiF:Ir(tppr) ₂ (dpm)	0.7:0.3:0.05
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	60	DBT3P-II:MoO ₃	1:0.5
	Electrode	101	70	ITSO	—

emission efficiency with low driving voltage and have excellent reliability: the LUMO level of the first organic compound is lower than that of the second organic compound, the HOMO level of the first organic compound is lower than that of the second organic compound, the LUMO level of the guest material is lower than that of the first organic compound, and the HOMO level of the guest material is lower than that of the second organic compound, the first organic compound and the second organic compound form an exciplex in combination with each other, and the energy difference between the HOMO level of the second organic compound and the LUMO level of the guest material is larger than or equal to the transition energy calculated from the absorption edge of the guest material or is larger than or equal to the light emission energy of the guest material.

As described above, by employing the structure of one embodiment of the present invention, a light-emitting element having high emission efficiency can be fabricated. A light-emitting element with reduced power consumption can be fabricated. A highly reliable light-emitting element can be fabricated.

EXAMPLE 3

In this example, a fabrication example of a light-emitting element (a light-emitting element 5) which is one embodiment of the present invention will be described. A schematic cross-sectional view of the light-emitting element fabricated in this example is similar to FIG. 34. Table 7 shows the detailed structure of the element. In addition, a structure and an abbreviation of a compound used here are given below. Note that Example 1 can be referred to for structures and abbreviations of other compounds.

<Fabrication of Light-Emitting Element 5>

The light-emitting element 5 was fabricated through the same steps as those for the light-emitting element 1 in the above example except for the steps of forming the light-emitting layer 160 and the electron-transport layer 118.

Next, as the light-emitting layer 160 of the light-emitting element 5, 2-{3-[3-(6-phenyldibenzothiophene-4-yl)phenyl]phenyl}dibenzo[f,h]quinoxaline (abbreviation: 2mDBTBPDBq-IV), PCBBiF, and Ir(tppr)₂(dpm) were deposited by co-evaporation in a weight ratio of 2mDBTBPDBq-IV:PCBBiF:Ir(tppr)₂(dpm)=0.7:0.3:0.05 to a thickness of 20 nm, and successively, 2mDBTBPDBq-IV, PCBBiF, and Ir(tppr)₂(dpm) were deposited by co-evaporation in a weight ratio of 2mDBTBPDBq-IV:PCBBiF:Ir(tppr)₂(dpm)=0.8:0.2:0.05 to a thickness of 20 nm. Note that in the light-emitting layer 160, 2mDBTBPDBq-IV corresponds to the first organic compound, PCBBiF corresponds to the second organic compound, and Ir(tppr)₂(dpm) corresponds to the guest material (the phosphorescent material). As the electron-transport layer 118, 2mDBTBPDBq-IV and NBPhen were sequentially deposited by evaporation to thicknesses of 30 nm and 15 nm, respectively, over the light-emitting layer 160.

<Characteristics of Light-Emitting Elements>

Next, the characteristics of the light-emitting element 5 were measured by a method similar to that in Example 1.

FIGS. 54, 55, 56, and 57 respectively show luminance-current density characteristics, luminance-voltage characteristics, current efficiency-luminance characteristics, and external quantum efficiency-luminance characteristics. FIG. 58 shows emission spectra when the current density in the light-emitting element 5 was 2.5 mA/cm². The measurement of the light-emitting element was performed at room temperature (in an atmosphere kept at 23° C.).

Table 8 shows element characteristics of the light-emitting element 5 at around 1000 cd/m².

TABLE 8

	Voltage (V)	Current density (mA/cm ²)	CIE chromaticity (x, y)	Luminance (cd/m ²)	Current efficiency (cd/A)	Power efficiency (lm/W)	External quantum efficiency (%)
Light-emitting element 5	3.40	2.75	(0.659, 0.340)	910	33.0	30.5	27.6

As shown in FIG. 58, the light-emitting element 5 emits red light. The electroluminescence spectrum of the light-emitting element 5 has a peak at a wavelength of 620 nm and a full width at half maximum of 80 nm.

As a result of measuring angular distributions of light emission of the light-emitting element 5, the Lambertian ratio was 94.5%. The external quantum efficiencies shown in Table 8 are each the product of the external quantum efficiency that was calculated from front luminance under assumption of Lambertian distribution and the Lambertian ratio for estimating true external quantum efficiency in consideration of luminous flux in every direction. Note that FIG. 57 shows both the external quantum efficiency calculated from luminance measured from the front under assumption of Lambertian distribution and the true one.

As shown in FIGS. 54 to 57 and Table 8, the light-emitting element 5 showed high current efficiency while exhibiting deep red with chromaticities x of 0.659. In addition, the maximum value of the external quantum efficiencies (true values) of the light-emitting element 5 was excellent, 28.2%. The light-emitting element 5 was driven at lower driving voltages; thus, the light-emitting element 5 showed excellent power efficiency.

The light emission starting voltages (a voltage at the time when the luminance exceeds 1 cd/m²) of the light-emitting element 5 was 2.3 V. This voltage is smaller than a voltage corresponding to an energy difference between the LUMO level and the HOMO level of the guest material Ir(tppr)₂(dpm), which was described in Example 1. The results suggest that emission in the light-emitting element 5 is obtained not by direct recombination of carriers in the guest material but by recombination of carriers in the material having a smaller energy gap.

<Results of CV Measurement>

The electrochemical characteristics (oxidation reaction characteristics and reduction reaction characteristics) of 2mDBTBPDBq-IV were measured by cyclic voltammetry (CV) measurement. Note that the measurement method is similar to that used in Example 1.

According to the CV measurement results, the oxidation potential of 2mDBTBPDBq-IV was 1.27 V, and the reduction potential thereof was 2.00 V. The HOMO level and the LUMO level of 2mDBTBPDBq-IV which were calculated from the CV measurement results were 6.21 eV and 2.94 eV, respectively. Note that as described in Example 1, the HOMO level and the LUMO level of PCBBiF were each 2.00 eV, and the HOMO level and the LUMO level of Ir(tppr)₂(dpm) were 5.57 eV and 3.05 eV, respectively.

Therefore, the LUMO level of the first organic compound (2mDBTBPDBq-IV) is lower than that of the second organic compound (PCBBiF), the HOMO level of the first organic compound (2mDBTBPDBq-IV) is lower than that of the second organic compound (PCBBiF), the LUMO level of the guest material (Ir(tppr)₂(dpm)) is lower than that of the first organic compound (2mDBTBPDBq-IV), and the HOMO level of the guest material (Ir(tppr)₂(dpm)) is higher than that of the second organic compound (PCBBiF).

The CV measurement results show that the combination of the first organic compound (2mDBTBPDBq-IV) and the second organic compound (PCBBiF) forms an exciplex.

Note that an energy difference between the LUMO level and the HOMO level of Ir(tppr)₂(dpm) was calculated to be 2.52 eV from the CV measurement results as described in Example 1.

As described above, the transition energy of Ir(tppr)₂(dpm) obtained from the absorption spectrum edge in FIG. 36 was 2.08 eV.

Thus, in Ir(tppr)₂(dpm), the energy difference between the LUMO level and the HOMO level was larger than the transition energy calculated from the absorption edge by 0.44 eV.

The light emission energy of Ir(tppr)₂(dpm) was determined as 1.98 eV because the peak wavelength on the shortest wavelength side of the emission spectrum in FIG. 36 was 625 nm.

Thus, in Ir(tppr)₂(dpm), the energy difference between the LUMO level and the HOMO level was larger than the light emission energy by 0.54 eV.

Consequently, in the guest material of the light-emitting element, the energy difference between the LUMO level and the HOMO level is larger than the transition energy calculated from the absorption edge by 0.4 eV or more. In addition, the energy difference between the LUMO level and the HOMO level is larger than the light emission energy by 0.4 eV or more. Therefore, high energy corresponding to the energy difference between the LUMO level and the HOMO level is needed, that is, high voltage is needed when carriers injected from a pair of electrodes are directly recombined in the guest material.

However, in the light-emitting element of one embodiment of the present invention, the guest material can be excited by energy transfer from an exciplex without the direct carrier recombination in the guest material, whereby the driving voltage can be lowered. Therefore, the light-emitting element of one embodiment of the present invention enables reduction in power consumption.

Note that an energy difference between the LUMO level of the first organic compound (2mDBTBPDBq-IV) and the HOMO level of the second organic compound (PCBBiF) was calculated to be 2.42 eV. Consequently, energy corresponding to the energy difference between the LUMO level and the HOMO level of an exciplex formed by the host materials is smaller than the energy difference between the LUMO level and the HOMO level (2.52 eV) of the guest material, but is larger than the transition energy (2.08 eV) calculated from the absorption edge of the guest material. Therefore, in the light-emitting element 5, the guest material can be excited through the exciplex, whereby the driving voltage can be lowered. Therefore, the light-emitting element of one embodiment of the present invention enables reduction in power consumption.

According to the CV measurement results, among carriers (electrons and holes) injected from the pair of electrodes, holes tend to be injected into the second organic compound

(PCBBiF) which is a host material with a high HOMO level, whereas electrons tend to be injected into the guest material (Ir(tppr)₂(dpm)) with a low LUMO level. That is, it seems at a glance that there is a possibility that an exciplex is formed by the second organic compound (PCBBiF) and the guest material (Ir(tppr)₂(dpm)).

However, an exciplex is not formed by the second organic compound and the guest material. This is shown by the fact that the emission spectrum of the light-emitting element 5 is close to that of Ir(tppr)₂(dpm) shown in FIG. 36. The present inventors found this characteristic phenomenon.

Thus, in the light-emitting element 5 containing Ir(tppr)₂(dpm), the energy difference (2.31 eV) between the HOMO level of the second organic compound and the LUMO level of the guest material (Ir(tppr)₂(dpm)) is larger than or equal to the transition energy (2.08 eV) calculated from the absorption spectrum edge of the guest material (Ir(tppr)₂(dpm)). In addition, the energy difference (2.31 eV) between the HOMO level of the second organic compound (PCBBiF) and the LUMO level of the guest material (Ir(tppr)₂(dpm)) is larger than or equal to the light emission energy (1.96 eV) of the guest material (Ir(tppr)₂(dpm)). Accordingly, transfer of excitation energy to the guest material is more facilitated eventually rather than formation of an exciplex by the combination of the second organic compound and the guest material, so that light emission from the guest material is efficiently obtained. This relationship is a feature of one embodiment of the present invention for efficient light emission.

<Results of Reliability Test>

Next, results of reliability tests of the light-emitting element 5 are shown in FIG. 59. Note that for the reliability tests, the current density and the initial luminance of the light-emitting element 5 were set to 50 mA/cm² and 14000 cd/m², respectively. The light-emitting element kept being driven with the current density maintained.

The time (LT90) taken for the luminance of the light-emitting element 5 to decrease to 90% of the initial luminance was 110 hours, which means the light-emitting element 5 shows high reliability.

A light-emitting element having the following structure like the light-emitting element 5 can achieve high emission efficiency with low driving voltage and have excellent reliability: the LUMO level of the first organic compound is lower than that of the second organic compound, the HOMO level of the first organic compound is lower than that of the second organic compound, the LUMO level of the guest material is lower than that of the first organic compound, and the HOMO level of the guest material is lower than that of the second organic compound, the first organic compound and the second organic compound form an exciplex in combination with each other, and the energy difference between the HOMO level of the second organic compound and the LUMO level of the guest material is larger than or equal to the transition energy calculated from the absorption

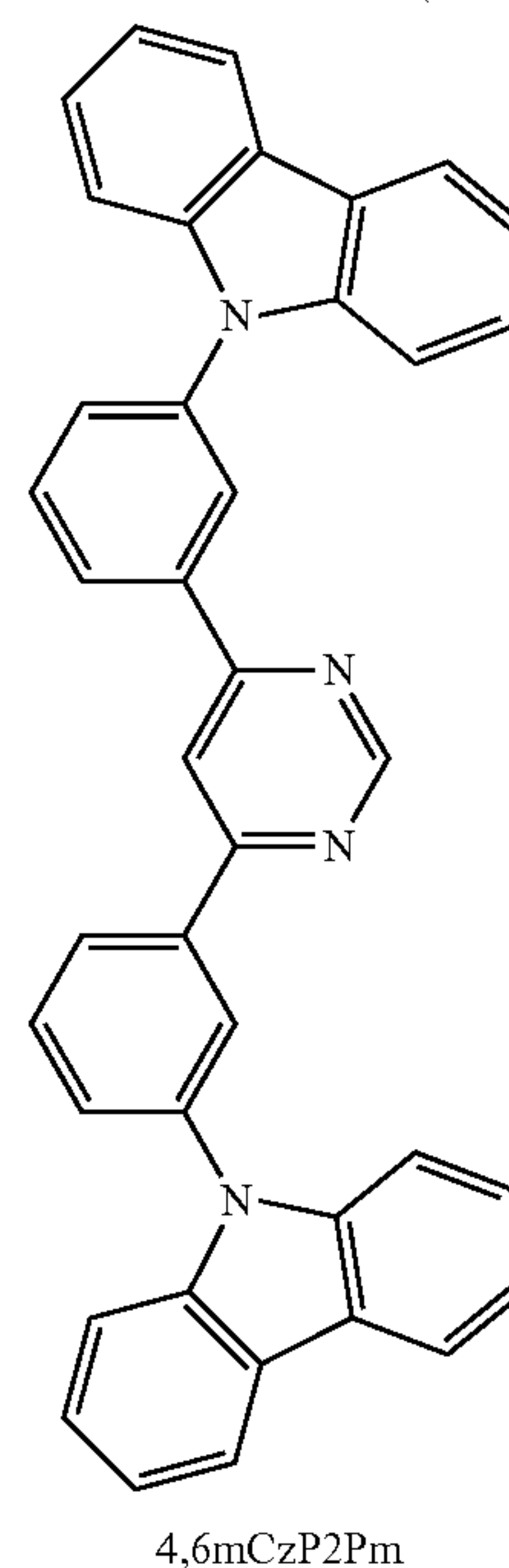
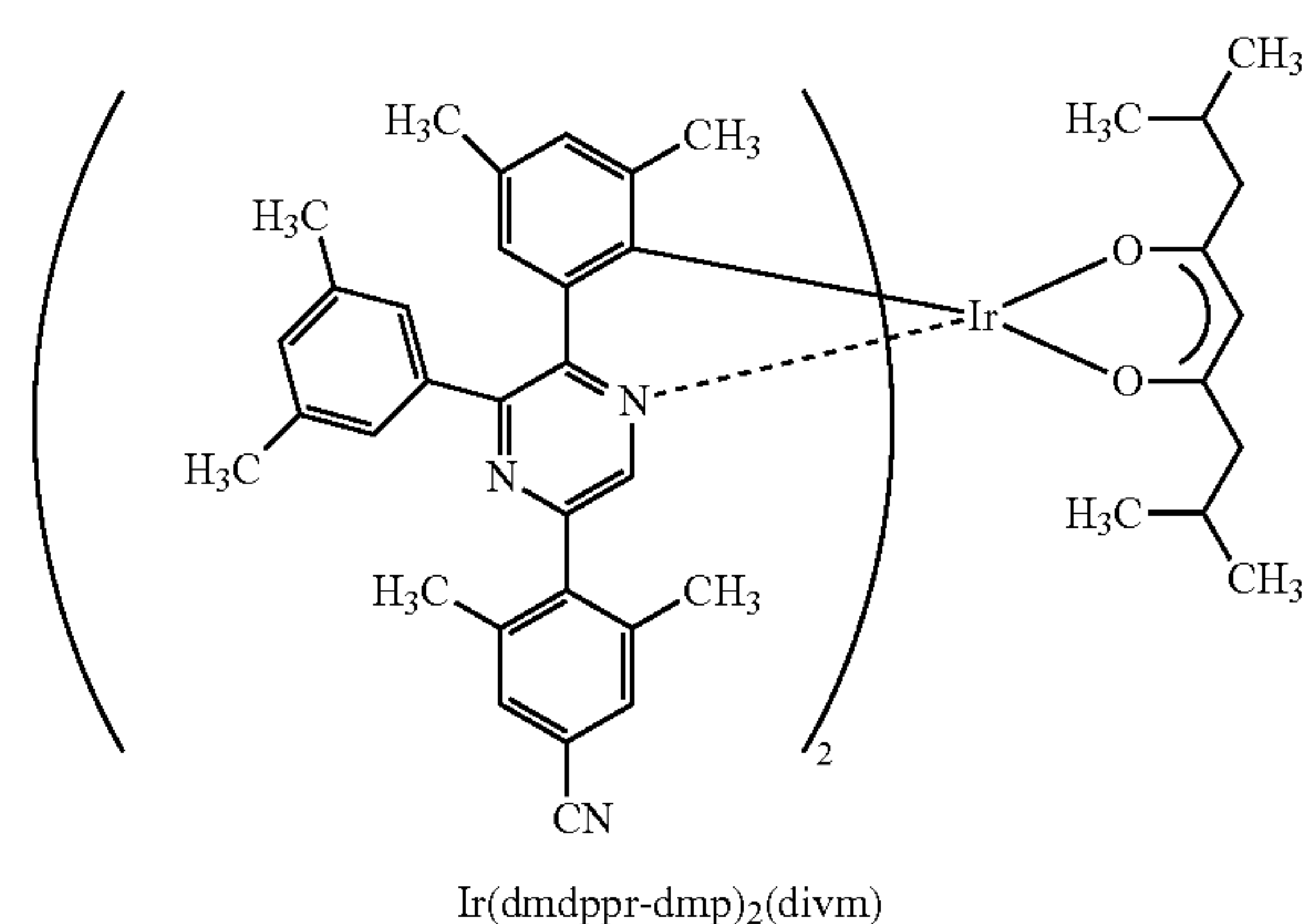
edge of the guest material or is larger than or equal to the light emission energy of the guest material.

As described above, by employing the structure of one embodiment of the present invention, a light-emitting element having high emission efficiency can be fabricated. A light-emitting element with reduced power consumption can be fabricated. A highly reliable light-emitting element can be fabricated.

EXAMPLE 4

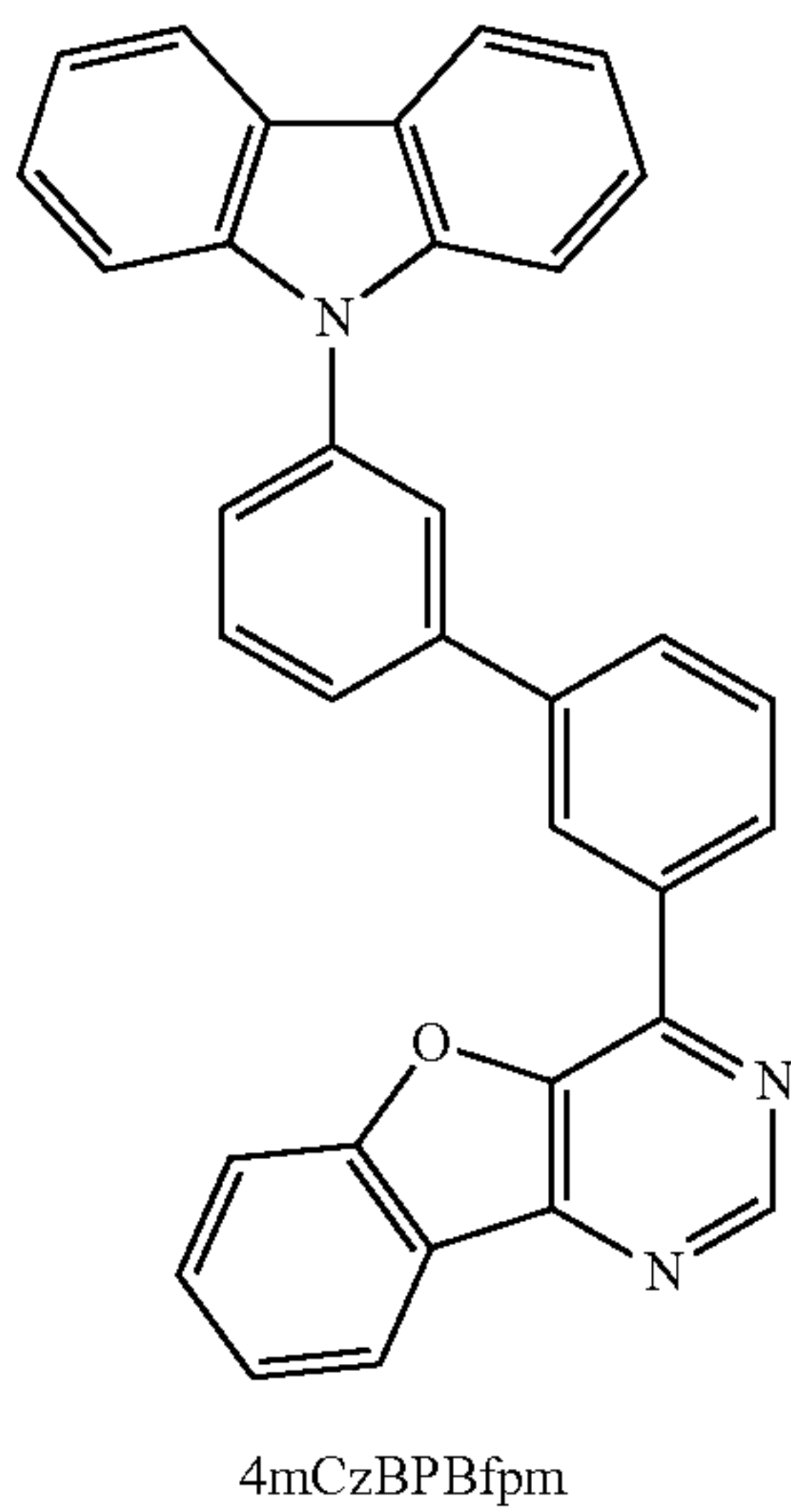
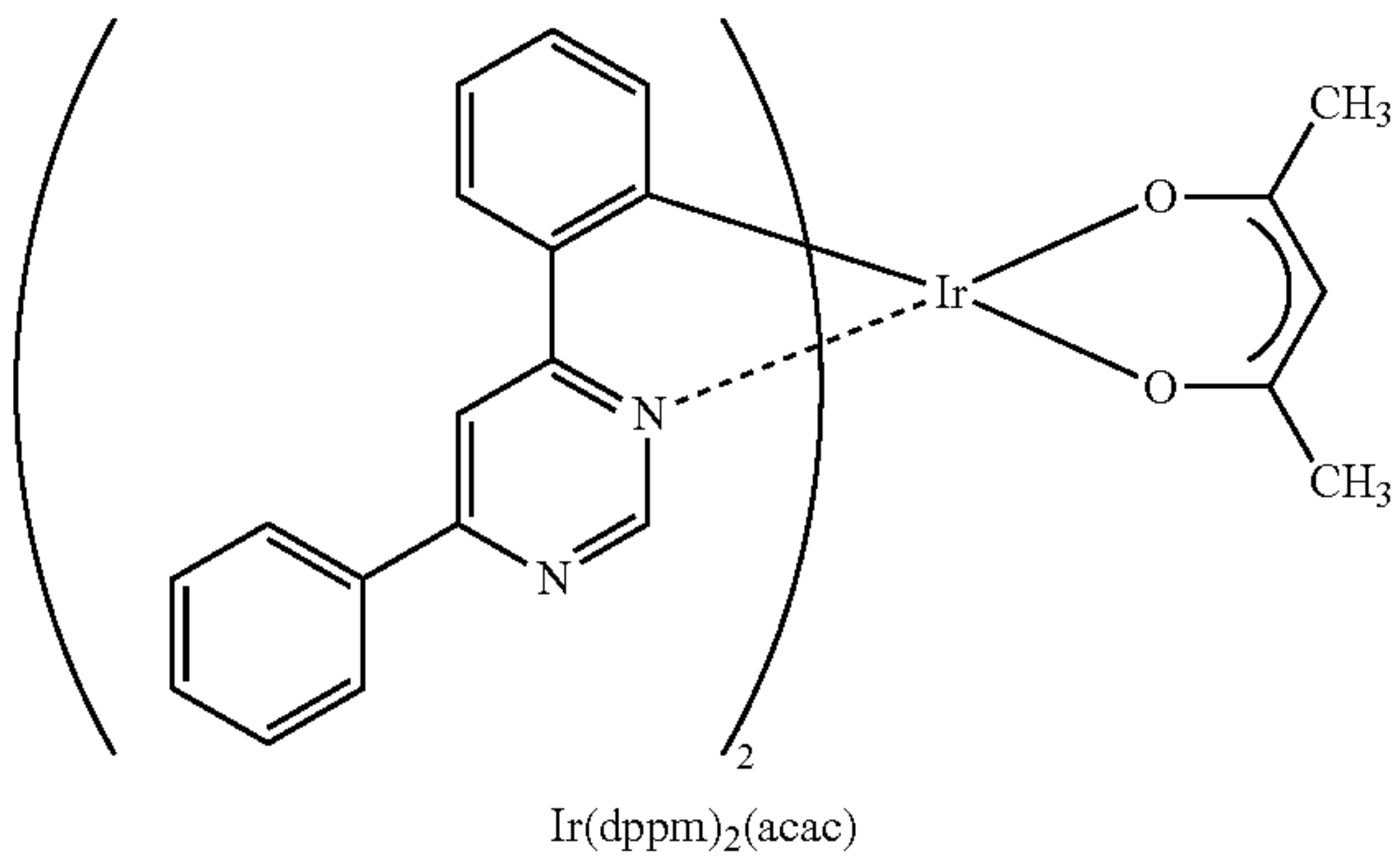
In this example, an example of fabricating light-emitting elements (light-emitting element 6 and 7) which is one embodiment of the present invention is described. FIG. 34 is a schematic cross-sectional view of each of the light-emitting elements fabricated in this example, and Table 9 shows details of the element structures. In addition, structures and abbreviations of compounds used here are given below. Note that Example 1 can be referred to for structures and abbreviations of other compounds.

[Chemical Formulae 4]



101

-continued



102

-continued

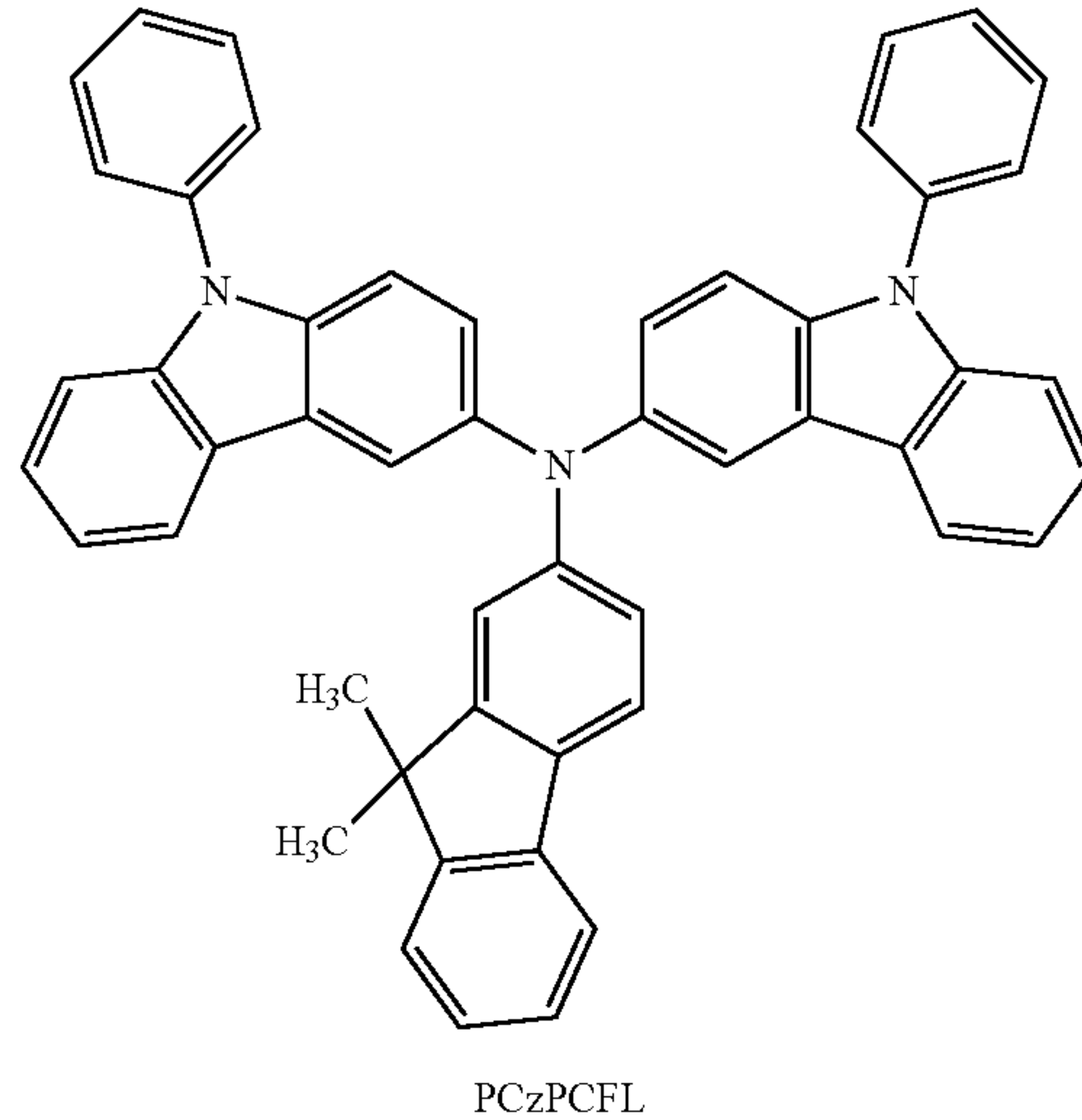
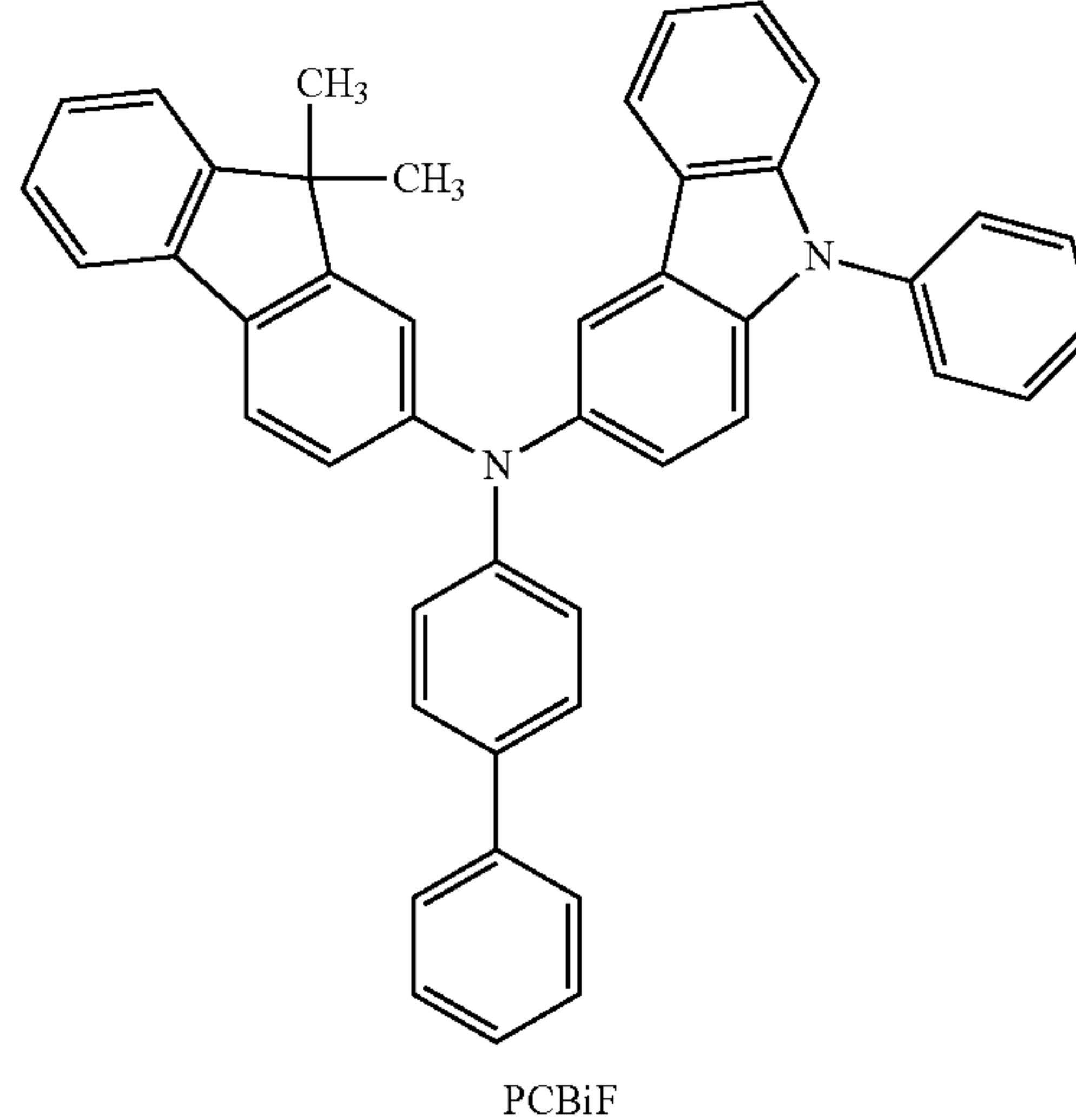


TABLE 9

	Layer	Reference	Thickness (nm)	Material	Weight ratio
Light-emitting element 6	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	10	BPhen	—
		118(1)	20	4,6mCzP2Pm	—
	Light-emitting layer	160	40	4,6mCzP2Pm:PCzPCFL:Ir(dmdppr-dmp) ₂ (divm)	0.8:0.2:0.05
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	60	DBT3P-II:MoO ₃	1:0.5
Light-emitting element 7	Electrode	101	70	ITSO	—
	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	10	BPhen	—
		118(1)	20	4mCzBPBfpm	—
	Light-emitting layer	160	40	4mCzBPBfpm:PCBiF:Ir(dppm) ₂ (acac)	0.8:0.2:0.05
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	60	DBT3P-II:MoO ₃	1:0.5
	Electrode	101	70	ITSO	—

<Fabrication of Light-Emitting Elements 6 and 7>

The light-emitting elements 6 and 7 were fabricated through the same steps as those for the light-emitting element 1 described in the above example except for the steps of forming the light-emitting layer **160** and the electron-transport layer **118**.

As the light-emitting layer **160** of the light-emitting element 6, 4,6mCzP2Pm, N-(9,9-dimethyl-9H-fluoren-2-yl)-9-phenyl-N-(9-phenyl-9H-carbazol-3-yl)-9H-carbazol-3-amine (abbreviation: PCzPCFL), and bis{4,6-dimethyl-2-[5-(2,6-dimethylphenyl)-3-(3,5-dimethylphenyl)-2-pyrazinyl-κN]phenyl-κC}(2,8-dimethyl-4,6-

nonanedionato-κ²O,O')iridium(III) (abbreviation: Ir(dmdppr-dmp)₂(divm)) were deposited by co-evaporation in a weight ratio of 4,6mCzP2Pm:PCzPCFL:Ir(dmdppr-dmp)₂(divm)=0.8:0.2:0.05 to a thickness of 40 nm. Note that in the light-emitting layer **160**, 4,6mCzP2Pm corresponds to the first organic compound, PCzPCFL corresponds to the second organic compound, and Ir(dmdppr-dmp)₂(divm) corresponds to the guest material (the phosphorescent material). As the electron-transport layer **118**, 4,6mCzP2Pm (as a layer **118(1)**) and BPhen (as a layer **118(2)**) were sequentially deposited by evaporation to thicknesses of 20 nm and 10 nm, respectively, over the light-emitting layer **160**.

As the light-emitting layer **160** of the light-emitting element 7, 4-{3-[3'-(9H-carbazol-9-yl)]biphenyl-3-yl}benzofuro[3,2-d]pyrimidine (abbreviation: 4mCzBPBfpm), PCBiF, and Ir(dppm)₂(acac) were deposited by co-evaporation in a weight ratio of 4mCzBPBfpm:PCBiF:Ir(dppm)₂(acac)=0.8:0.2:0.05 and a thickness of 40 nm. Note that in the light-emitting layer **160**, 4mCzBPBfpm corresponds to the first organic compound, PCBiF corresponds to the second organic compound, and Ir(dppm)₂(acac) corresponds to the guest material (the phosphorescent material). As the electron-transport layer **118**, 4mCzBPBfpm (as a layer **118(1)**) and BPhen (as a layer **118(2)**) were sequentially deposited by evaporation to thicknesses of 20 nm and 10 nm, respectively, over the light-emitting layer **160**.

<Characteristics of Light-Emitting Elements>

Next, the characteristics of the light-emitting elements 6 and 7 were measured by a method similar to that in Example 1.

FIGS. **60** to **63** show luminance-current density characteristics, luminance-voltage characteristics, current efficiency-luminance characteristics, and external quantum efficiency-luminance characteristics, respectively, of the light-emitting elements 6 and 7. FIG. **64** shows the

electroluminescence spectra of the light-emitting element 6 and 7 through which current flows at a current density of 2.5 mA/cm². The measurements of the light-emitting elements were performed at room temperature (in an atmosphere kept at 23° C.). The external quantum efficiency in this example was calculated by measuring luminance from the front on the assumption of light distribution on a perfectly diffusing surface (also referred to as Lambertian surface).

Table 10 shows element characteristics of the light-emitting elements 6 and 7 at around 1000 cd/m².

TABLE 10

	Voltage (V)	Current density (mA/cm ²)	CIE chromaticity (x, y)	Luminance (cd/m ²)	Current efficiency (cd/A)	Power efficiency (lm/W)	External quantum efficiency (%)
Light-emitting element 6	3.50	2.57	(0.667, 0.333)	1080	41.8	37.5	28.7
Light-emitting element 7	2.80	1.18	(0.550, 0.448)	1110	94.2	106	33.2

As shown in FIG. **64**, the electroluminescence spectra of red light and orange light from the light-emitting elements 6 and 7 have peak wavelengths at 616 nm and 579 nm, respectively, and full widths at half maximum of 48 nm and 71 nm, respectively.

From FIG. **60** to FIG. **63** and Table 10, it is found that the light-emitting elements 6 and 7 have high current efficiency. The maximum external quantum efficiencies of the light-emitting elements 6 and 7 were 30.0% and 33.9%, which are excellent values. As shown in FIG. **61**, the light-emitting elements 6 and 7 were driven at lower driving voltages; thus, the light-emitting elements 6 and 7 showed excellent power efficiency.

The light emission starting voltages (a voltage at the time when the luminance exceeds 1 cd/m²) of the light-emitting elements 6 and 7 were 2.4 V and 2.2 V, respectively. The voltages are smaller than a voltage corresponding to an energy difference between the LUMO level and the HOMO level of the guest materials Ir(dmdppr-dmp)₂(divm) and Ir(dppm)₂(acac), which is described later. The results suggest that emission in the light-emitting elements 6 and 7 are obtained not by direct recombination of carriers in the guest material but by recombination of carriers in the material having a smaller energy gap.

<Emission Spectra of Host Materials>

In the light-emitting elements, 4,6mCzP2Pm alone, 4mCzBPBfpm alone, PCzPCFL alone, and PCBiF alone were used as host materials (the first organic compound and the second organic compound). FIG. **65** shows measurement results of emission spectra of thin films of these host materials. The measurement method was similar to that used in Example 1.

As in FIGS. **65A** and **65B**, peak wavelengths of the emission spectra of the thin films of 4,6mCzP2Pm alone, 4mCzBPBfpm alone, PCzPCFL alone, and PCBiF alone were 439 nm, 440 nm, 448 nm, and 430 nm, respectively, showing blue light emission.

<Fabrication of Comparative Light-Emitting Elements>

Next, comparative light-emitting elements 1 and 2 not containing guest materials were fabricated as comparative light-emitting elements for the light-emitting elements 6 and 7. The characteristics of the comparative light-emitting elements 1 and 2 were evaluated. The detailed element structures are shown in Table 11.

TABLE 11

	Layer	Reference	Thickness (nm)	Material	Weight ratio
Comparative light-emitting element 1	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	10	BPhen	—
		118(1)	20	4,6mCzP2Pm	—
	Light-emitting layer	160	40	4,6mCzP2Pm:PCzPCFL	0.8:0.2
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	60	DBT3P-II:MoO ₃	1:0.5
	Electrode	101	70	ITSO	—
Comparative light-emitting element 2	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	10	BPhen	—
		118(1)	20	4mCzBPBfpm	—
	Light-emitting layer	160	40	4mCzBPBfpm:PCBiF	0.8:0.2
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	60	DBT3P-II:MoO ₃	1:0.5
	Electrode	101	70	ITSO	—

The comparative light-emitting elements 1 and 2 were fabricated through the same steps as those for the light-emitting elements 6 and 7 except for the steps of forming the light-emitting layer **160**.

As the light-emitting layer **160** of the comparative light-emitting element 1, 4,6mCzP2Pm and PCzPCFL were deposited by co-evaporation in a weight ratio of 4,6mCzP2Pm:PCzPCFL=0.8:0.2 and a thickness of 40 nm.

As the light-emitting layer **160** of the comparative light-emitting element 2, 4mCzBPBfpm and PCBiF were deposited by co-evaporation in a weight ratio of 4mCzBPBfpm:PCBiF=0.8:0.2 and a thickness of 40 nm.

<Characteristics of Comparative Light-Emitting Elements>

Next, the characteristics of the comparative light-emitting elements 1 and 2 were measured by a method similar to that in Example 1.

FIGS. **66** to **69** respectively show luminance-current density characteristics, luminance-voltage characteristics, current efficiency-luminance characteristics, and external quantum efficiency-luminance characteristics of the comparative light-emitting elements 1 and 2. FIG. **70** shows emission spectra when the current density in the comparative light-emitting elements 1 and 2 was 2.5 mA/cm². The measurements of the light-emitting elements were performed at room temperature (in an atmosphere kept at 23° C.).

Table 12 shows the element characteristics of the comparative light-emitting elements 1 and 2 at around 1000 cd/m².

TABLE 12

	Voltage (V)	Current density (mA/cm ²)	CIE chromaticity (x, y)	Luminance (cd/m ²)	Current efficiency (cd/A)	Power efficiency (lm/W)	External quantum efficiency (%)
Comparative light-emitting element 1	3.50	3.46	(0.476, 0.512)	950	27.4	24.6	9.1
Comparative light-emitting element 2	3.00	1.81	(0.443, 0.542)	970	53.3	55.8	15.7

As shown in FIG. **70**, the electroluminescence spectra of yellow light from the comparative light-emitting elements 1 and 2 have peak wavelengths at 564 nm and 557 nm, respectively, and full widths at half maximum of 103 nm and 88 nm, respectively. The light emission spectra are greatly

different from those of the thin films of 4,6mCzP2Pm alone, 4mCzBPBfpm alone, PCzPCFL alone, and PCBiF alone shown in FIG. **65**.

As described later, the LUMO level of 4,6mCzP2Pm is lower than that of PCzPCFL, and the HOMO level of PCzPCFL is higher than that of 4,6mCzP2Pm. The energy of light emission from the comparative light-emitting element 1 including the mixed thin film of 4,6mCzP2Pm and PCzPCFL approximately corresponds to an energy difference between the LUMO level of 4,6mCzP2Pm and the HOMO level of PCzPCFL. The light emission from the comparative light-emitting element 1 including the mixed thin film of 4,6mCzP2Pm and PCzPCFL has a longer wavelength (lower energy) than light emission from 4,6mCzP2Pm alone and light emission from PCzPCFL alone. Therefore, it can be said that the light emission of the comparative light-emitting element 1 is derived from an exciplex formed by the two compounds. That is, a combination of organic compounds 4,6mCzP2Pm and PCzPCFL forms an exciplex, and thus the use of 4,6mCzP2Pm and PCzPCFL as host materials can fabricate a light-emitting element utilizing ExtET.

As described later, the LUMO level of 4mCzBPBfpm is lower than that of PCBiF, and the HOMO level of PCBiF is higher than that of 4mCzBPBfpm. The energy of light emission from the comparative light-emitting element 2 including the mixed thin film of 4mCzBPBfpm and PCBiF approximately corresponds to an energy difference between the LUMO level of 4mCzBPBfpm and the HOMO level of

PCBiF. The light emission from the comparative light-emitting element 2 including the mixed thin film of 4mCzBPBfpm and PCBiF has a longer wavelength (lower energy) than light emission from 4mCzBPBfpm alone and light emission from PCBiF alone. Therefore, it can be said

that the light emission of the comparative light-emitting element 2 is derived from an exciplex formed by the two compounds. That is, a combination of organic compounds 4mCzBPBfpm and PCBiF forms an exciplex, and thus the use of 4mCzBPBfpm and PCBiF as host materials can fabricate a light-emitting element utilizing ExtET.

From FIG. 66 to FIG. 69 and Table 12, it is found that the comparative light-emitting elements 1 and 2 have higher emission efficiency. In addition, the maximum values of the external quantum efficiencies of the comparative light-emitting elements 1 and 2 were excellent, 10.3% and 15.5%, respectively. Since the probability of formation of singlet excitons which are generated by recombination of carriers (holes and electrons) injected from the pair of electrodes is at most 25%, the external quantum efficiency in the case where the light extraction efficiency to the outside is 25% is at most 6.3%. The light-emitting elements 1 and 2 achieved external quantum efficiency of higher than 6.3%. This is because the light-emitting elements 1 and 2 emit, in addition to light originating from singlet excitons generated by recombination of carriers (holes and electrons) injected from the pair of electrodes, light originating from singlet excitons generated from triplet excitons by ExEF. It is thus found that the comparative light-emitting elements 1 and 2 emits light originating from an exciplex having a function of exhibiting thermally activated delayed fluorescence

As shown in FIG. 67, the comparative light-emitting elements 1 and 2 were driven at low driving voltage. Accordingly, the comparative light-emitting elements 1 and 2 show excellent power efficiency. The light emission starting voltages (a voltage at the time when the luminance is higher than 1 cd/m²) of the comparative light-emitting elements 1 and 2 were 2.4 V and 2.2 V, respectively. These voltages are to the same as those of the light-emitting elements 6 and 7. The results show that emission in the light-emitting elements 6 and 7 are obtained by recombination of carriers in the first organic compound and the second organic compound which are host materials, as in the comparative light-emitting elements 1 and 2.

<Absorption Spectra and Light Emission Spectra of Guest Materials>

FIG. 71 shows the measurement results of the absorption spectrum and the emission spectrum of Ir(dmdppr-dmp)₂(divm) which is the guest material of the light-emitting element 6. FIG. 72 shows the measurement results of the absorption spectrum and the emission spectrum of Ir(dppm)₂(acac) which is the guest material of the light-emitting element 7. Note that the measurement method was similar to that used in Example 1.

As shown in FIG. 71 and FIG. 72, the absorption bands on the lowest energy side (on the longest wavelength side) of the absorption spectra of Ir(dmdppr-dmp)₂(divm) and Ir(dppm)₂(acac) are observed at around 580 nm and 520 nm, respectively. In addition, the absorption spectrum edges were obtained from data on the absorption spectra and transition energies were estimated on the assumption of direct transfer. According to the calculation, the absorption edge of Ir(dmdppr-dmp)₂(divm) and transition energy were 608 nm and 2.04 eV, respectively; and the absorption edge of Ir(dppm)₂(acac) and the transition energy thereof were 559 nm and 2.22 eV, respectively.

The results show that the absorption band on the lowest energy side (the longest wavelength side) of the absorption spectrum of Ir(dmdppr-dmp)₂(divm) has a region overlapping with the emission of the exciplex formed by 4,6mCzP2Pm and PCzPCFL. Therefore, in the light-emitting element 6 containing 4,6mCzP2Pm and PCzPCFL as

host materials, excitation energy can be effectively transferred to the guest material. In addition, the absorption band on the lowest energy side (the longest wavelength side) of the absorption spectrum of Ir(dppm)₂(acac) has a region overlapping with the emission of the exciplex formed by 4mCzBPBfpm and PCBiF. Therefore, in the light-emitting element 7 containing 4mCzBPBfpm and PCBiF as host materials, excitation energy can be effectively transferred to the guest material.

As described above, the light-emitting element 6 contains the host materials 4,6mCzP2Pm (the first organic compound) and PCzPCFL (the second organic compound) that form an exciplex in combination. The light-emitting element 7 contains the host materials 4mCzBPBfpm (the first organic compound) and PCBiF (the second organic compound) that form an exciplex in combination.

<Phosphorescence Spectra of Host Materials>

FIG. 73 shows the measurement results of the triplet excitation energy level of 4,6mCzP2Pm, which was used as a host material. FIG. 74 shows the measurement results of the triplet excitation energy level of 4mCzBPBfpm. FIG. 75 shows the measurement results of the triplet excitation energy level of PCzPCFL. FIG. 76 shows the measurement results of the triplet excitation energy level of PCBiF. Note that the measurement method was similar to that used in Example 1.

As shown in FIGS. 73 to 76, peak wavelengths on the shortest wavelength sides of the phosphorescence emission spectra of 4,6mCzP2Pm, 4mCzBPBfpm, PCzPCFL, and PCBiF were 459 nm, 462 nm, 513 nm, and 507 nm, respectively. Thus, their triplet excitation energy levels of them derived from the results were 2.70 eV, 2.68 eV, 2.42 eV, and 2.45 eV, respectively.

A peak wavelength on the shortest wavelength side of the phosphorescence emission spectrum of each of 4,6mCzP2Pm and PCzPCFL is shorter than a peak wavelength on the shortest wavelength side of the light emission spectrum of the comparative light-emitting element 1 (the light emission spectrum of an exciplex formed by 4,6mCzP2Pm and PCzPCFL) which is shown in FIG. 70. A peak wavelength on the shortest wavelength side of the phosphorescence emission spectrum of each of 4mCzBPBfpm and PCBiF is shorter than a peak wavelength on the shortest wavelength side of the light emission spectrum of the comparative light-emitting element 2 (the light emission spectrum of an exciplex formed by 4mCzBPBfpm and PCBiF) which is shown in FIG. 70. Note that the exciplex has a feature in that an energy difference between the singlet excitation energy level and the triplet excitation energy level is small and thus the triplet excitation energy level of the exciplex can be obtained from a peak wavelength on the shortest wavelength side of the emission spectrum. Accordingly, the triplet excitation energy level of each of 4,6mCzP2Pm (the first organic compound) and PCzPCFL (the second organic compound) is higher than the triplet excitation energy level of the exciplex formed by themselves. The triplet excitation energy level of each of 4mCzBPBfpm (the first organic compound) and PCBiF (the second organic compound) is higher than the triplet excitation energy level of the exciplex formed by themselves. The peak wavelengths on the shortest wavelength sides of the phosphorescence emission spectra of 2mDBTBPDq-II and PCBiF are shorter than the peak wavelength, which has been shown in FIG. 35, on the shortest wavelength side of the emission spectrum of the exciplex formed by 2mDBTBPDq-II and PCBiF. The exciplex is characterized by a small energy difference between the singlet excitation

energy level and the triplet excitation energy level; accordingly, the triplet excitation energy level of the exciplex can be derived from the peak wavelength on the shortest wavelength side of the emission spectrum. Thus, the triplet excitation energy levels of the first organic compound (2mDBTBPDq-II) and the second organic compound (PCBiF) are higher than the triplet excitation energy level of the exciplex.

The triplet excitation energy levels of 4,6mCzP2Pm and PCzPCFL are higher than the transition energy of Ir(dmdppr-dmp)₂(divm), 2.04 eV, which was derived from the absorption spectrum edge shown in FIG. 71. In addition, the triplet excitation energy levels of 4mCzBPBfpm and PCBiF are higher than the transition energy of Ir(dppm)₂(acac), 2.22 eV, which was derived from the absorption spectrum edge shown in FIG. 72.

Therefore, the first organic compounds (4,6mCzP2Pm and 4mCzBPBfpm) and the second organic compounds (PCzPCFL and PCBiF), which were used as host materials in this example, have triplet excitation energy levels high enough for host materials.

<Results of CV Measurement>

The electrochemical characteristics (oxidation reaction characteristics and reduction reaction characteristics) of the compounds used as the host materials (the first organic compound and the second organic compound) and the guest material in the above-described light-emitting elements were examined by cyclic voltammetry (CV). The measurement method was similar to that used in Example 1.

Table 13 shows oxidation potentials and reduction potentials obtained by CV measurement and HOMO levels and LUMO levels of the compounds calculated from the CV measurement results. Note that the LUMO level of PCBiF is probably high because the reduction potential of PCBiF is low and a clear reduction peak is not observed.

TABLE 13

Abbreviation	Oxidation potential (V)	Reduction potential (V)	HOMO level calculated from oxidation potential (eV)	LUMO level calculated from reduction potential (eV)
Ir(dmdppr-dmp) ₂ (divm)	0.55	-2.04	-5.49	-2.91
Ir(dppm) ₂ (acac)	0.62	-1.96	-5.56	-2.98
4,6mCzP2Pm	0.95	-2.06	-5.89	-2.88
4mCzBPBfpm	0.97	-1.97	-5.91	-2.97
PCzPCFL	0.20	-2.90	-5.14	-2.05
PCBiF	0.32	—	-5.26	—

As shown in Table 13, in the light-emitting element 6, the reduction potential of the first organic compound (4,6mCzP2Pm) is higher than that of the second organic compound (PCzPCFL), the oxidation potential of the first organic compound (4,6mCzP2Pm) is higher than that of the second organic compound (PCzPCFL), the reduction potential of the guest material Ir(dmdppr-dmp)₂(divm) is higher than that of the first organic compound (4,6mCzP2Pm), and the oxidation potential of the guest material Ir(dmdppr-dmp)₂(divm) is higher than that of the second organic compound (PCzPCFL). Therefore, the LUMO level of the first organic compound (4,6mCzP2Pm) is lower than that of the second organic compound (PCzPCFL), the HOMO level of the first organic compound (4,6mCzP2Pm) is lower than that of the second organic compound (PCzPCFL), the LUMO level of the guest material (Ir(dmdppr-dmp)₂(divm)) is lower than that of the first organic compound

(4,6mCzP2Pm), and the HOMO level of the guest material (Ir(dmdppr-dmp)₂(divm)) is higher than that of the second organic compound (PCzPCFL).

In the light-emitting element 7, the reduction potential of the first organic compound (4mCzBPBfpm) is higher than that of the second organic compound (PCBiF), the oxidation potential of the first organic compound (4mCzBPBfpm) is higher than that of the second organic compound (PCBiF), the reduction potential of the guest material Ir(dppm)₂(acac) is higher than that of the first organic compound (4mCzBPBfpm), and the oxidation potential of the guest material Ir(dppm)₂(acac) is higher than that of the second organic compound (PCBiF). Therefore, the LUMO level of the first organic compound (4mCzBPBfpm) is lower than that of the second organic compound (PCBiF), the HOMO level of the first organic compound (4mCzBPBfpm) is lower than that of the second organic compound (PCBiF), the LUMO level of the guest material Ir(dppm)₂(acac) is lower than that of the first organic compound (4mCzBPBfpm), and the HOMO level of the guest material Ir(dppm)₂(acac) is higher than that of the second organic compound (PCBiF).

The CV measurement results show that the combination of 4,6mCzP2Pm (the first organic compound) and PCzPCFL (the second organic compound) forms an exciplex and the combination of 4mCzBPBfpm (the first organic compound) and PCBiF (the second organic compound) forms an exciplex.

Note that an energy difference between the LUMO level and the HOMO level of Ir(dmdppr-dmp)₂(divm) was calculated to be 2.59 eV and that of Ir(dppm)₂(acac) was calculated to be 2.58 eV from the CV measurement results shown in Table 13.

As described above, the transition energies of Ir(dmdppr-dmp)₂(divm) and Ir(dppm)₂(acac) obtained from the absorption spectrum edge in FIGS. 71 and 72 were 2.04 eV and 2.22 eV, respectively.

The results show that the energy difference between the LUMO level and the HOMO level of Ir(dmdppr-dmp)₂(divm) is larger than the transition energy thereof calculated from the absorption edge by 0.55 eV and that the energy difference between the LUMO level and the HOMO level of Ir(dppm)₂(acac) is larger than the transition energy thereof calculated from the absorption edge by 0.36 eV.

The light emission energy of Ir(dmdppr-dmp)₂(divm) was calculated to be 2.03 eV from the peak wavelength on the shortest wavelength side of the light emission spectrum in FIG. 71 was 611 nm. The light emission energy of Ir(dppm)₂(acac) was calculated to be 2.09 eV from the peak wavelength on the shortest wavelength side of the light emission spectrum in FIG. 72 was 592 nm.

The results show that the energy difference between the LUMO level and the HOMO level of Ir(dmdppr-dmp)₂(divm) is larger than the transition energy thereof by 0.56 eV and that the energy difference between the LUMO level and the HOMO level of Ir(dppm)₂(acac) is larger than the transition energy thereof by 0.49 eV.

Consequently, in each of the guest materials of the light-emitting elements, the energy difference between the LUMO level and the HOMO level is larger than the transition energy calculated from the absorption edge by 0.3 eV or more. In addition, the energy difference between the LUMO level and the HOMO level is larger than the light emission energy by 0.4 eV or more. Therefore, high energy corresponding to the energy difference between the LUMO level and the HOMO level is needed, that is, high voltage is needed when carriers injected from a pair of electrodes are directly recombined in the guest material.

However, in the light-emitting element of one embodiment of the present invention, the guest material can be excited by energy transfer from an exciplex without the direct carrier recombination in the guest material, whereby the driving voltage can be lowered. Therefore, the light-

emitting element of one embodiment of the present invention enables reduction in power consumption.

Note that an energy difference between the LUMO level of the first organic compound (4,6mCzP2Pm) and the HOMO level of the second organic compound (PCzPCFL), which were host materials of the light-emitting element 6, was calculated to be 2.26 eV from Table 3. Consequently, energy corresponding to the energy difference between the LUMO level and the HOMO level of an exciplex formed by the host materials is smaller than the energy difference between the LUMO level and the HOMO level (2.59 eV) of the guest material, and larger than the transition energy (2.04 eV) calculated from the absorption edge of the guest material. Note that an energy difference between the LUMO level of the first organic compound (4mCzBPBfpm) and the HOMO level of the second organic compound (PCBiF), which are host materials of the light-emitting element 7, was calculated to be 2.29 eV from Table 3. Consequently, energy corresponding to the energy difference between the LUMO level and the HOMO level of an exciplex formed by the host materials is smaller than the energy difference between the LUMO level and the HOMO level (2.58 eV) of the guest material (Ir(mpptz-diBuCNp)₃), and larger than the transition energy (2.22 eV) calculated from the absorption edge of the guest material. Therefore, in the light-emitting elements 6 and 7, the guest materials can be excited through the exciplex, whereby the driving voltage can be lowered. Therefore, the light-emitting element of one embodiment of the present invention enables reduction in power consumption.

According to the CV measurement results in Table 13, among carriers (electrons and holes) injected from the pair of electrodes, holes tend to be injected into the second organic compounds (PCzPCFL and PCBBiF) which are host materials with a high HOMO level, whereas electrons tend to be injected into the guest materials (Ir(dmdppr-dmp)₂(divm) and (Ir(pidrpim)₂(acac)) with a low LUMO level. That is, it seems at a glance that there is a possibility that an exciplex is formed by the second organic compound (PCzPCFL) and the guest material Ir(dmdppr-dmp)₂(divm) or by the second organic compound (PCBiF) and the guest material (Ir(dppm)₂(acac)).

However, an exciplex is not formed by the second organic compound and the guest materials. This is shown by the fact that the electroluminescence spectra of the light-emitting elements 6 and 7 are close to those of the guest materials (Ir(dmdppr-dmp)₂(divm) and (Ir(pidrpim)₂(acac)) shown in FIGS. 71 and 72. The present inventors found this characteristic phenomenon.

According to the CV measurement results in Table 13, an energy difference between the HOMO level of the second organic compound PCzPCFL and the LUMO level of the guest material Ir(dmdppr-dmp)₂(divm) of the light-emitting element 6 was calculated to be 2.23 eV, and an energy difference between the HOMO level of the second organic compound PCBiF and the LUMO level of the guest material Ir(dppm)₂(acac) of the light-emitting element 7 was calculated to be 2.28 eV.

Thus, in the light-emitting element 6 containing Ir(dmdppr-dmp)₂(divm), the energy difference (2.23 eV) between the HOMO level of the second organic compound (PCzPCL) and the LUMO level of the guest material (Ir(dmdppr-dmp)₂(divm)) is larger than or equal to the transition energy (2.04 eV) calculated from the absorption edge of the absorption spectrum of the guest material (Ir(dmdppr-dmp)₂(divm)). In addition, the energy difference (2.23 eV) between the HOMO level of the second organic compound (PCzPCFL) and the LUMO level of the guest material (Ir(dmdppr-dmp)₂(divm)) is larger than or equal to the light emission energy (2.03 eV) of the guest material (Ir(dmdppr-dmp)₂(divm)). In the light-emitting element 7 containing Ir(dppm)₂(acac), the energy difference (2.28 eV) between

the HOMO level of the second organic compound (PCBiF) and the LUMO level of the guest material (Ir(dppm)₂(acac)) is larger than or equal to the transition energy (2.22 eV) calculated from the absorption edge of the absorption spectrum of the guest material (Ir(dppm)₂(acac)). In addition, the energy difference (2.28 eV) between the HOMO level of the second organic compound (PCBiF) and the LUMO level of the guest material (Ir(dppm)₂(acac)) is larger than or equal to the light emission energy (2.09 eV) of the guest material (Ir(dppm)₂(acac)). Accordingly, in the light-emitting elements 6 and 7, transfer of excitation energy to the guest material is more facilitated eventually rather than formation of an exciplex by the combination of the second organic compound and the guest material, so that light emission from the guest material is efficiently obtained. This relationship is a feature of one embodiment of the present invention for efficient light emission.

A light-emitting element having the following structure like the light-emitting elements 6 and 7 can achieve high emission efficiency with low driving voltage: the LUMO level of the first organic compound is lower than that of the second organic compound, the HOMO level of the first organic compound is lower than that of the second organic compound, the LUMO level of the guest material is lower than that of the first organic compound, the HOMO level of the guest material is lower than that of the second organic compound, the first organic compound and the second organic compound form an exciplex in combination with each other, and the energy difference between the HOMO level of the second organic compound and the LUMO level of the guest material is larger than or equal to the transition energy calculated from the absorption edge of the absorption spectrum of the guest material or is larger than or equal to the light emission energy of the guest material.

As described above, by employing the structure of one embodiment of the present invention, a light-emitting element having high emission efficiency can be fabricated. Furthermore, a light-emitting element with reduced power consumption can be fabricated.

EXAMPLE 5

In this example, an example of fabricating a light-emitting element (a light-emitting element 8) of one embodiment of the present invention is described. A schematic cross-sectional view of the light-emitting elements fabricated in this example is similar to FIG. 34. Table 14 shows the detailed structures of the elements. In addition, a structure and an abbreviation of a compound used here are given below. For the structures and abbreviations of other compounds used in this embodiment, those in Examples described above can be referred to.

[Chemical Formula 5]

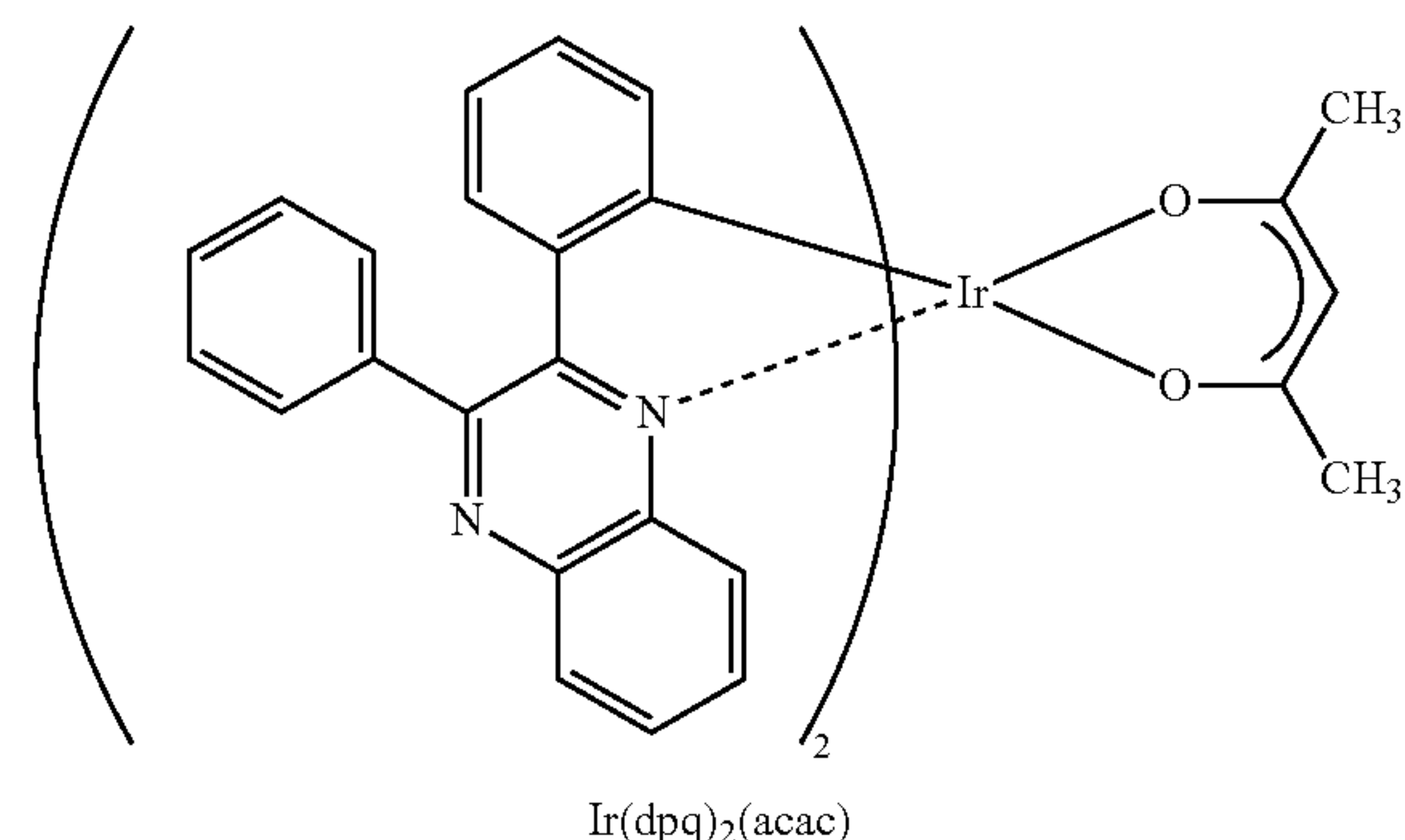


TABLE 14

	Layer	Reference	Thickness (nm)	Material	Weight ratio
Light-emitting element 8	Electrode	102	200	Al	—
	Electron-injection layer	119	1	LiF	—
	Electron-transport layer	118(2)	10	BPhen	—
		118(1)	20	2mDBTBPDBq-II	—
	Light-emitting layer	160	40	2mDBTBPDBq-II:PCBBiF:Ir(dpq) ₂ (acac)	0.8:0.2:0.05
	Hole-transport layer	112	20	BPAFLP	—
	Hole-injection layer	111	20	DBT3P-II:MoO ₃	1:0.5
	Electrode	101	110	ITSO	—

<Fabrication of Light-Emitting Element 8>

The light-emitting element 8 was fabricated through the same steps as those for the light-emitting element 3 in Example 2 except for the steps of forming the light-emitting layer 160.

As the light-emitting layer 160 of the light-emitting element 8, 2mDBTBPDBq-II, PCBBiF, bis(2,3-diphenylquinoxalinato)iridium(III) acetylacetonate (abbreviation: Ir(dpq)₂(acac)) were deposited by co-evaporation with a weight ratio of 2mDBTBPDBq-II:PCBBiF:Ir(dpq)₂(acac)=0.8:0.2:0.05 and to a thickness of 40 nm. Note that in the light-emitting layer 160, 2mDBTBPDBq-II corresponds to the first organic compound, PCBBiF corresponds to the second organic compound, and Ir(dpq)₂(acac) corresponds to the guest material (the phosphorescent material).

<Characteristics of Light-Emitting Elements>

Next, the characteristics of the light-emitting element 8 was measured by a method similar to that in Example 1.

FIGS. 77 to 80 respectively show luminance-current density characteristics, luminance-voltage characteristics, current efficiency-luminance characteristics, and external quantum efficiency-luminance characteristics of the light-emitting element 8. FIG. 81 shows the emission spectrum of the light-emitting element 8, through which a current flows at a current density of 2.5 mA/cm². The measurements of the light-emitting elements were performed at room temperature (in an atmosphere kept at 23° C.). The external quantum efficiency in this example was calculated by measuring luminance from the front on the assumption of light distribution on a perfectly diffusing surface (also referred to as Lambertian).

Table 15 shows element characteristics of the light-emitting element 8 at around 1000 cd/m².

TABLE 15

	Voltage (V)	Current density (mA/cm ²)	CIE chromaticity (x, y)	Luminance (cd/m ²)	Current efficiency (cd/A)	Power efficiency (lm/W)	External quantum efficiency (%)
Light-emitting element 8	8.80	172	(0.734, 0.261)	940	0.55	0.19	4.42

As shown in FIG. 81, the light-emitting element 8 emits red light in which the electroluminescence spectrum has a peak at a wavelength of 675 nm and a full width at half maximum of 61 nm.

As shown in FIGS. 77 to 80 and Table 15, the light-emitting element 8 showed high current efficiency while exhibiting very deep red with chromaticities x of 0.734.

As shown in FIG. 78, the light emission starting voltage (a voltage at the time when the luminance exceeds 1 cd/m²) of the light-emitting element 8 was 3 V or lower and the driving voltage thereof was low.

<Absorption Spectrum and Emission Spectrum of Guest Material>

FIG. 82 shows the measurement results of the absorption spectrum and the emission spectrum of Ir(dpq)₂(acac) that is the guest material of the light-emitting element 8. The measurement method was similar to that used in Example 1.

As shown in FIG. 82, an absorption band on the lowest energy side (the longest wavelength side) of the absorption spectrum of Ir(dpq)₂(acac) is at around 630 nm. The absorption edge was calculated from data of the absorption spectrum, and a transition energy was estimated on the assumption of direct transition, whereby it was found that the absorption edge of the absorption spectrum of Ir(dpq)₂(acac) was at 670 nm and transition energy thereof was 1.85 eV.

As shown in FIG. 35 in Example 1, 2mDBTBPDBq-II and PCBBiF are organic compounds which form an exciplex in combination with each other. The exciplex exhibits a broad emission spectrum from 430 nm to 650 nm.

Therefore, the absorption bands of the absorption spectrum of Ir(dpq)₂(acac) on the lowest energy side (the longest wavelength side) has a region that overlaps with light emission by an exciplex formed by 2mDBTBPDBq-II and PCBBiF, which means that in the light-emitting element 8 containing 2mDBTBPDBq-II and PCBBiF as the host materials, excitation energy can be transferred effectively to the guest material.

As shown in Example 1, T1 levels of 2mDBTBPDBq-II and PCBBiF are 2.41 eV and 2.44 eV, respectively, which are higher than the transition energy calculated from the absorption spectrum edge of the guest material (Ir(dpq)₂(acac)).

Therefore, the first organic compound (2mDBTBPDBq-II) and the second organic compound (PCBBiF), which were

used as host materials in this example, have triplet excitation energy levels high enough for host materials.

<Results of CV Measurement>

The electrochemical characteristics (oxidation reaction characteristics and reduction reaction characteristics) of Ir(dpq)₂(acac) used as the guest material in the light-emitting element 8 were measured by cyclic voltammetry (CV). The measurement method was similar to that used in Example 1.

According to the CV measurement results, the oxidation potential of Ir(dpq)₂(acac) was 0.66 V, and the reduction

potential thereof was 1.80 V. In addition, the HOMO level and the LUMO level of $\text{Ir}(\text{dpq})_2(\text{acac})$ which were calculated from the CV measurement results were -5.51 eV and -3.06 eV, respectively. Note that Table 3 in Example 1 can be referred to for the measurement results of 2mDBTBPDBq-II and PCBBiF.

The results of the CV measurement show that the LUMO level of the first organic compound (2mDBTBPDBq-II) is lower than that of the second organic compound (PCBBiF), the HOMO level of the first organic compound (2mDBTBPDBq-II) is lower than that of the second organic compound (PCBBiF), the LUMO level of the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$) is lower than the LUMO level of the first organic compound (2mDBTBPDBq-II), and the HOMO level of the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$) is lower than the HOMO level of the second organic compound (PCBBiF).

The results of the CV measurement show that the combination of the first organic compound (2mDBTBPDBq-II) and the second organic compound (PCBBiF) forms an exciplex.

An energy difference between the LUMO level and the HOMO level of $\text{Ir}(\text{dpq})_2(\text{acac})$ was 2.45 eV, calculated from the CV measurement results.

As described above, the transition energy of $\text{Ir}(\text{dpq})_2(\text{acac})$ obtained from the absorption spectrum edge in FIG. 82 was 1.85 eV.

That is, the energy difference between the LUMO level and the HOMO level of $\text{Ir}(\text{dpq})_2(\text{acac})$ is larger than the transition energy thereof calculated from the absorption edge by 0.60 eV.

The peak wavelength of the maximum value on the shortest wavelength side of the electroluminescence spectrum in FIG. 82 is 678 nm. According to that, the light emission energy of $\text{Ir}(\text{dpq})_2(\text{acac})$ was calculated to be 1.83 eV.

That is, the energy difference between the LUMO level and the HOMO level of $\text{Ir}(\text{dpq})_2(\text{acac})$ was larger than the light emission energy by 0.62 eV.

Consequently, in the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$) of the light-emitting element 8, the energy difference between the LUMO level and the HOMO level is larger than the transition energy calculated from the absorption edge by 0.3 eV or more. In addition, the energy difference between the LUMO level and the HOMO level is larger than the light emission energy by 0.4 eV or more. Therefore, high energy corresponding to the energy difference between the LUMO level and the HOMO level is needed, that is, high voltage is needed when carriers injected from a pair of electrodes are directly recombined in the guest material.

However, in the light-emitting element of one embodiment of the present invention, the guest material can be excited by energy transfer from an exciplex without the direct carrier recombination in the guest material, whereby the driving voltage can be lowered. Therefore, the light-emitting element of one embodiment of the present invention can have reduced power consumption.

Note that as shown in Table 3, an energy difference between the LUMO level of the first organic compound (2mDBTBPDBq-II) and the HOMO level of the second organic compound (PCBBiF) (2mDBTBPDBq-II and PCBBiF are the host materials) was calculated to be 2.42 eV. Consequently, energy corresponding to the energy difference between the LUMO level and the HOMO level of an exciplex formed by the host materials is smaller than the energy difference (2.45 eV) between the LUMO level and the HOMO level of the guest material $\text{Ir}(\text{dpq})_2(\text{acac})$, and larger than the transition energy (1.85 eV) calculated from

the absorption edge. Therefore, in the light-emitting element 8, the guest material can be excited through the exciplex, whereby the driving voltage can be lowered. Therefore, the light-emitting element of one embodiment of the present invention can have reduced power consumption.

According to the CV measurement results, among carriers (electrons and holes) injected from the pair of electrodes, holes tend to be injected into the second organic compound (PCBBiF) which is a host material with a high HOMO level, whereas electrons tend to be injected into the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$) with a low LUMO level. That is, it seems at a glance that there is a possibility that an exciplex is formed by the second organic compound (PCBBiF) and the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$).

However, an exciplex is not formed by the second organic compound and the guest material. This is shown by the fact that the electroluminescence spectrum of the light-emitting element 8 are similar to the emission spectrum of the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$) shown in FIG. 82. The present inventors have found this characteristic phenomenon.

The energy difference between the HOMO level of the second organic compound (PCBBiF) and the LUMO level of the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$) was calculated to be 2.30 eV from the CV measurement results.

In the light-emitting element 8, the energy difference (2.30 eV) between the HOMO level of the second organic compound and the LUMO level of the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$) is higher than or equal to the transition energy (1.85 eV) calculated from the absorption edge of the absorption spectrum of the guest material. Furthermore, the energy difference (2.30 eV) between the HOMO level of the second organic compound and the LUMO level of the guest material ($\text{Ir}(\text{dpq})_2(\text{acac})$) is higher than or equal to the energy (1.83 eV) of the light emission exhibited by the guest material. Accordingly, rather than formation of an exciplex by the combination of the second organic compound and the guest material, transfer of excitation energy to the guest material is more facilitated eventually, whereby efficient light emission from the guest material is achieved. This relationship is a feature of one embodiment of the present invention which contributes to efficient light emission.

<Results of Reliability Test>

Next, results of reliability tests of the light-emitting element 8 are shown in FIG. 83. Note that for the reliability tests, the current density and the initial luminance of the light-emitting element 8 were set to 75 mA/cm^2 and 500 cd/m^2 , respectively. The light-emitting element kept being driven with the current density maintained.

The time (LT90) taken for the luminance of the light-emitting element 8 to decrease to 90% of the initial luminance was 410 hours, which means the light-emitting element 8 shows high reliability.

A light-emitting element having the following structure like the light-emitting element 8 can achieve high emission efficiency with low driving voltage and have excellent reliability: the LUMO level of the first organic compound is lower than that of the second organic compound, the HOMO level of the first organic compound is lower than that of the second organic compound, the LUMO level of the guest material is lower than that of the first organic compound, and the HOMO level of the guest material is lower than that of the second organic compound, the first organic compound and the second organic compound form an exciplex in combination with each other, and the energy difference between the HOMO level of the second organic compound and the LUMO level of the guest material is larger than or equal to the transition energy calculated from the absorption

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edge of the guest material or is larger than or equal to the light emission energy of the guest material.

As described above, by employing the structure of one embodiment of the present invention, a light-emitting element having high emission efficiency can be provided. Furthermore, a light-emitting element with reduced power consumption can be manufactured. A highly reliable light-emitting element can be provided.

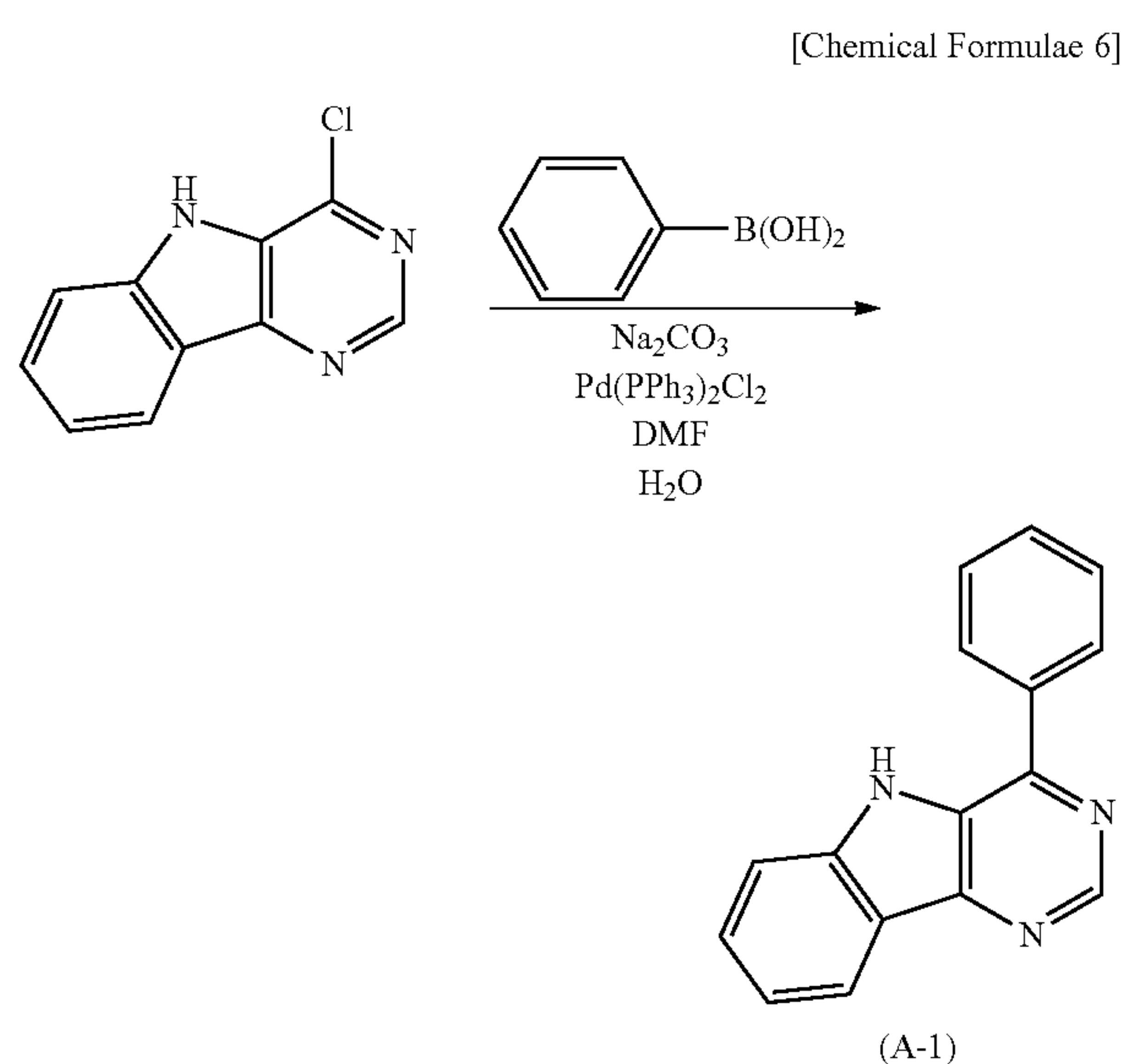
REFERENCE EXAMPLE 1

In this reference example, a method of synthesizing bis[2-(5-ethyl-5H-4-pyrimido[5,4-b]indolyl- κ N3)phenyl- κ C](2,4-pentanedionato- κ^2 O,O')iridium(III) (abbreviation: Ir(pidrpm)₂(acac)), which is an organometallic complex used in Example 2, is described.

SYNTHESIS EXAMPLE 1

Step 1: Synthesis of
4-phenyl-5H-PYRIMIDO[5,4-b]indole

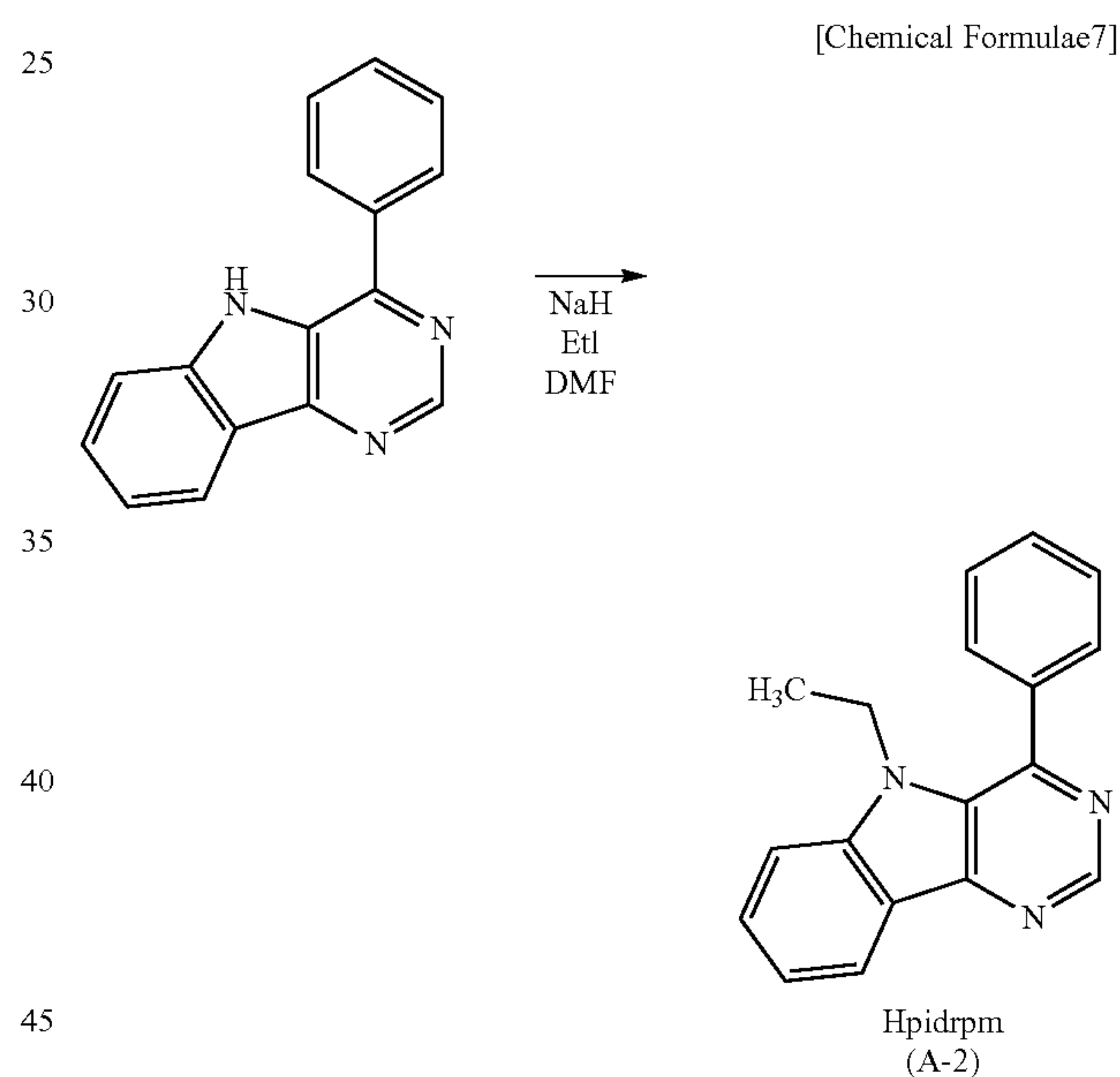
First, 1.00 g of 4-chloro-5H-pyrimido[5,4-b]indole, 0.90 g of phenylboronic acid, 0.78 g of sodium carbonate, 0.020 g of bis(triphenylphosphine)palladium(II) dichloride (abbreviation: Pd(PPh₃)₂Cl₂), 20 mL of water, and 20 mL of DMF were put into a recovery flask equipped with a reflux pipe, and the air in the flask was replaced with argon. Then, this reaction container was subjected to irradiation with microwave (2.45 GHz, 100 W) for 1 hour to be heated and reacted. After that, water was added to this reaction solution and an organic layer was extracted with dichloromethane. The obtained solution of the extract was washed with saturated brine, and magnesium sulfate was added for drying. The solution obtained by the drying was filtrated. The solvent of this filtrate was distilled off, and then the obtained residue was purified by silica gel column chromatography using ethyl acetate as a developing solvent, so that 4-phenyl-5H-pyrimido[5,4-b]indole, which was the desired pyrimidine derivative, was obtained as a yellowish white powder in a yield of 75%. Note that the irradiation with microwaves was performed using a microwave synthesis system (Discover, manufactured by CEM Corporation). A synthesis scheme of Step 1 is shown in (A-1).



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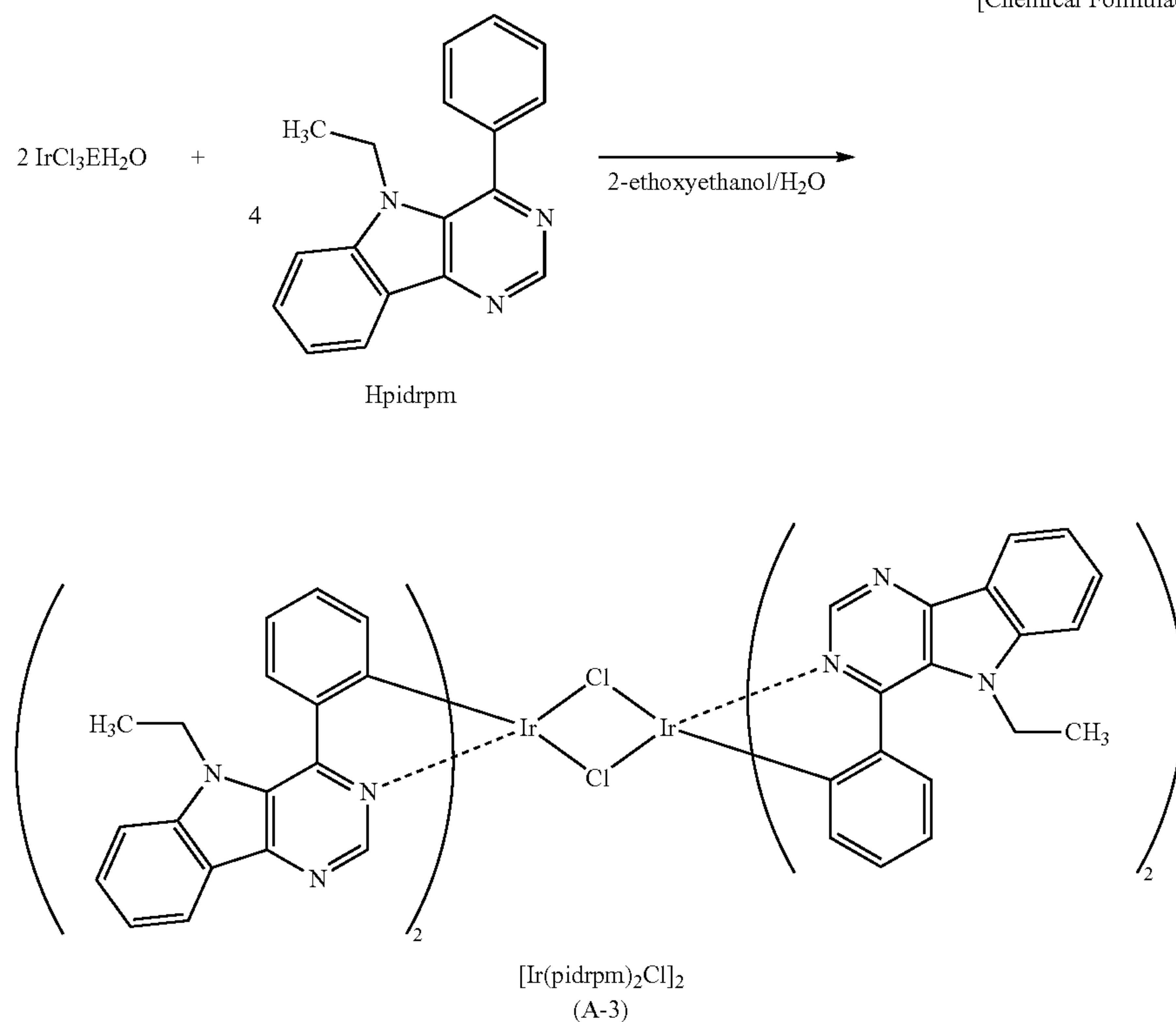
Step 2: Synthesis of
5-ethyl-4-phenylpyrimido[5,4-b]indole
(abbreviation: Hpidrpm)

Next, 0.89 g of 4-phenyl-5H-pyrimido[5,4-b]indole obtained in Step 1 and 18 mL of dry DMF were put into a 100-mL three-neck flask and the air in the flask was replaced with nitrogen. Then, sodium hydride (60% dispersion in paraffin liquid, 0.44 g) was added to this mixture, and the mixture was stirred at room temperature for 30 minutes. Then, 0.58 mL of iodoethane was added dropwise, and the mixture was stirred at room temperature for 18 hours. Then, 100 mL of water was poured into the obtained reaction solution, and the precipitated solid was collected by suction filtration. The obtained solid was purified by silica gel column chromatography using ethyl acetate as a developing solvent, so that Hpidrpm, which was the desired pyrimidine derivative, was obtained as a yellowish white powder in a yield of 78%. A synthesis scheme of Step 2 is shown in (A-2).

Step 3: Synthesis of di- μ -chloro-tetrakis[2-(5-ethyl-5H-4-pyrimido[5,4-b]indolyl- κ N3)phenyl- κ C]diiridium(III) (abbreviation: [Ir(pidrpm)₂Cl]₂)

Next, into a recovery flask equipped with a reflux pipe were put 15 mL of 2-ethoxyethanol, 5 mL of water, 0.91 g of Hpidrpm obtained in Step 2, and 0.48 g of iridium chloride hydrate (IrCl₃·xH₂O) (produced by Heraeus K.K.), and the air in the flask was replaced with argon. After that, irradiation with microwaves (2.45 GHz, 100 W) was performed for 1 hour to cause a reaction. The solvent of this reaction solution was distilled off, and methanol was added to the obtained residue and this mixture was suction-filtered. The obtained solid was washed with methanol to give [Ir(pidrpm)₂Cl]₂, which is a dinuclear complex, as a reddish brown powder in a yield of 78%. A synthesis scheme of Step 3 is shown in (A-3) given below.

[Chemical Formulae 8]

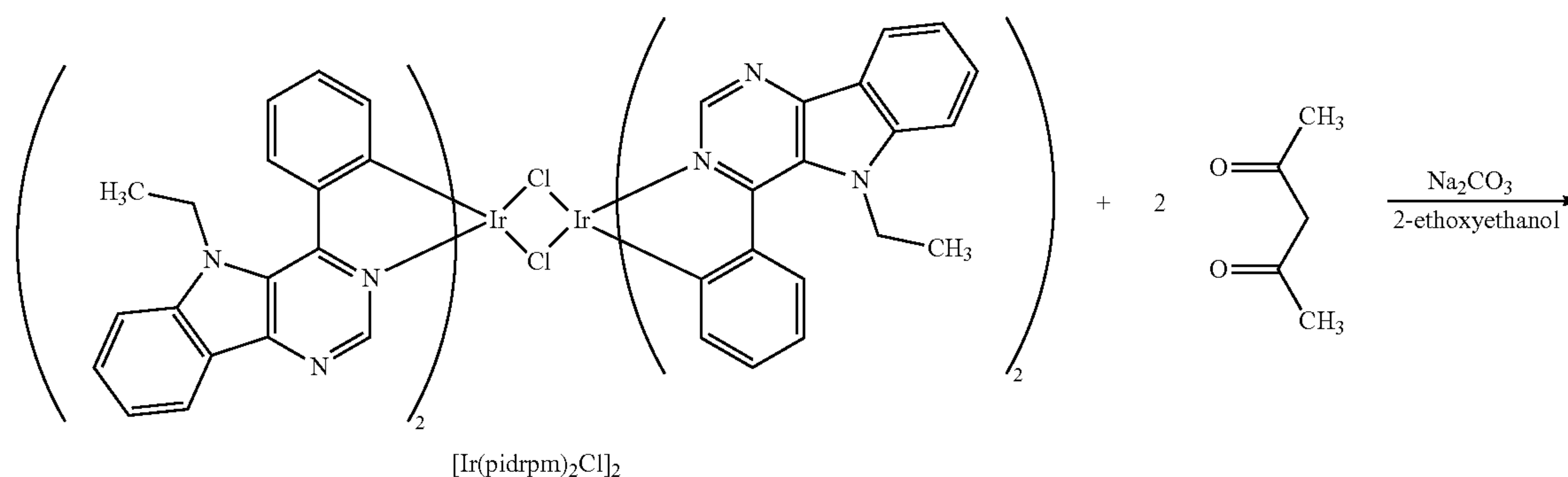


Step 4: Synthesis of bis[2-(5-ethyl-5H-4-pyrimido
[5,4-b]indolyl-κN3)phenyl-κC](2,4-pentanedionato-
κ²O,O')iridium(III) (abbreviation: [Ir(pidrpm)₂
(acac)]

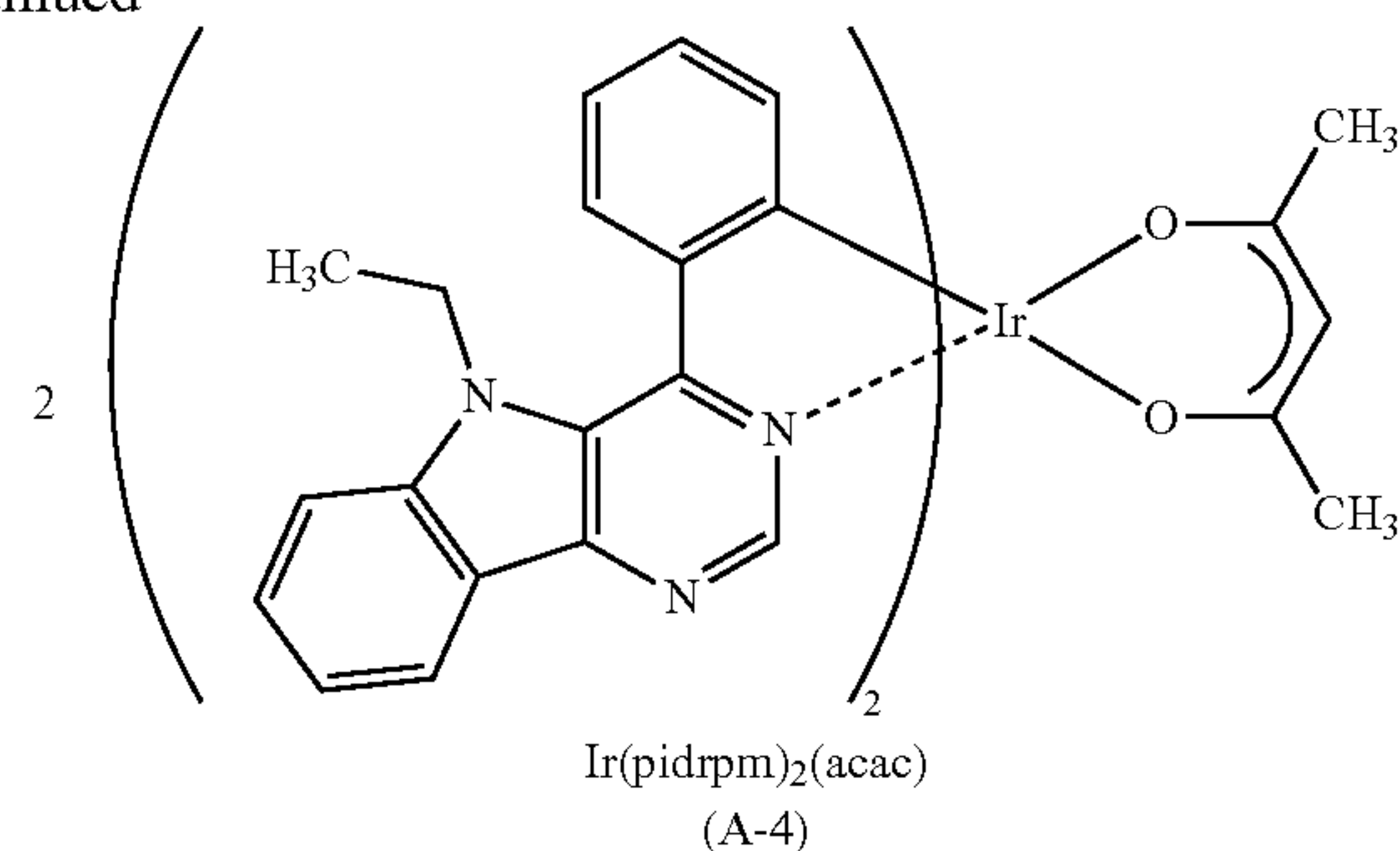
Next, into a recovery flask equipped with a reflux pipe
were put 20 mL of 2-ethoxyethanol, 0.97 g of [Ir(pidrpm)₂
Cl]₂, which was the dinuclear complex obtained in Step 3, 40
0.19 g of acetylacetonate (abbreviation: Hacac), and 0.67 g of
sodium carbonate, and the air in the flask was replaced with
argon. Then, irradiation with microwaves (2.45 GHz, 100
W) was performed for 60 minutes. Here, 0.19 g of Hacac 45
(abbreviation) was added, and irradiation with microwaves
(2.45 GHz, 100 W) was performed again for 60 minutes for
heating and reaction. The solvent of this reaction solution
was distilled off, and methanol was added to the obtained

residue and this mixture was suction-filtered. The obtained
solid was washed with water and methanol. After the
obtained solid was purified by flash column chromatography
using hexane and ethyl acetate as a developing solvent in a
ratio of 2:1, recrystallization was carried out with a mixed
solvent of dichloromethane and methanol; thus, [Ir(pidrpm)₂
(acac)], which is the organometallic complex of one embodi-
ment of the present invention, was obtained as a red powder
in a yield of 56%. By train sublimation, 0.48 g of the
obtained red powder was purified. In the purification by
sublimation, the red powder was heated at 285° C. under a
pressure of 2.7 Pa with an argon flow rate of 5 mL/min. After
the purification by sublimation, a red solid of the desired
substance was obtained in a yield of 83%. A synthetic
scheme of Step 4 is shown in (A-4) below.

[Chemical Formulae 9]



-continued



Note that analysis results by nuclear magnetic resonance (¹H-NMR) spectroscopy of the red powder obtained in Step 4 are described below.

¹H-NMR.δ (CDCl₃): 1.06 (t, 6H), 1.74 (s, 6H), 4.65-4.81 (m, 4H), 5.19 (s, 1H), 6.54 (d, 2H), 6.75 (t, 2H), 6.97 (t, 2H), 7.46 (t, 2H), 7.69-7.75 (m, 4H), 7.88 (d, 2H), 8.41 (d, 2H), 9.07 (s, 2H).

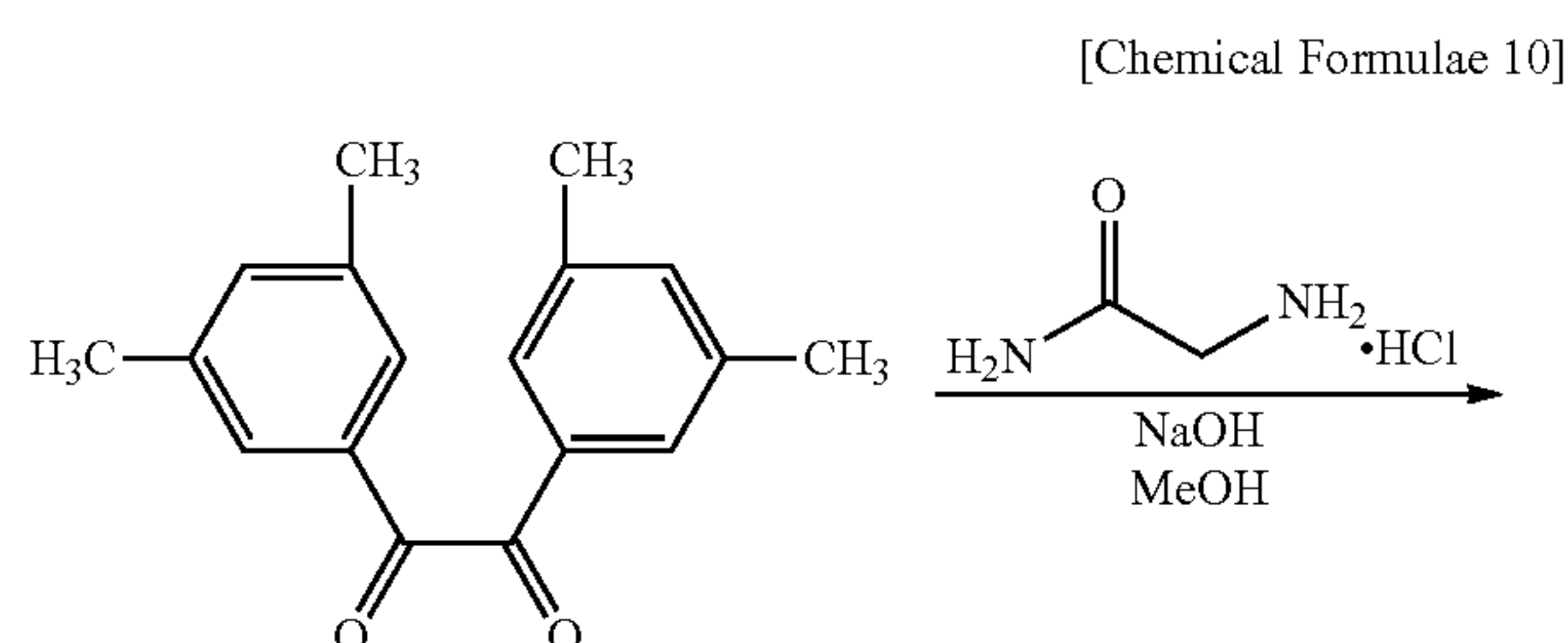
REFERENCE EXAMPLE 2

In this reference example, a synthesis method of bis{4, 6-dimethyl-2-[5-(4-cyano-2,6-dimethylphenyl)-3-(3,5-dimethylphenyl)-2-pyrazinyl-κN]phenyl-κC}(2,2,6,6-tetramethyl-3,5-heptanedionate-κ²O,O')iridium(III) (abbreviation: Ir(dmdppr-dmCP)₂(dpm)]), the organometallic iridium complex used in Example 2, is described.

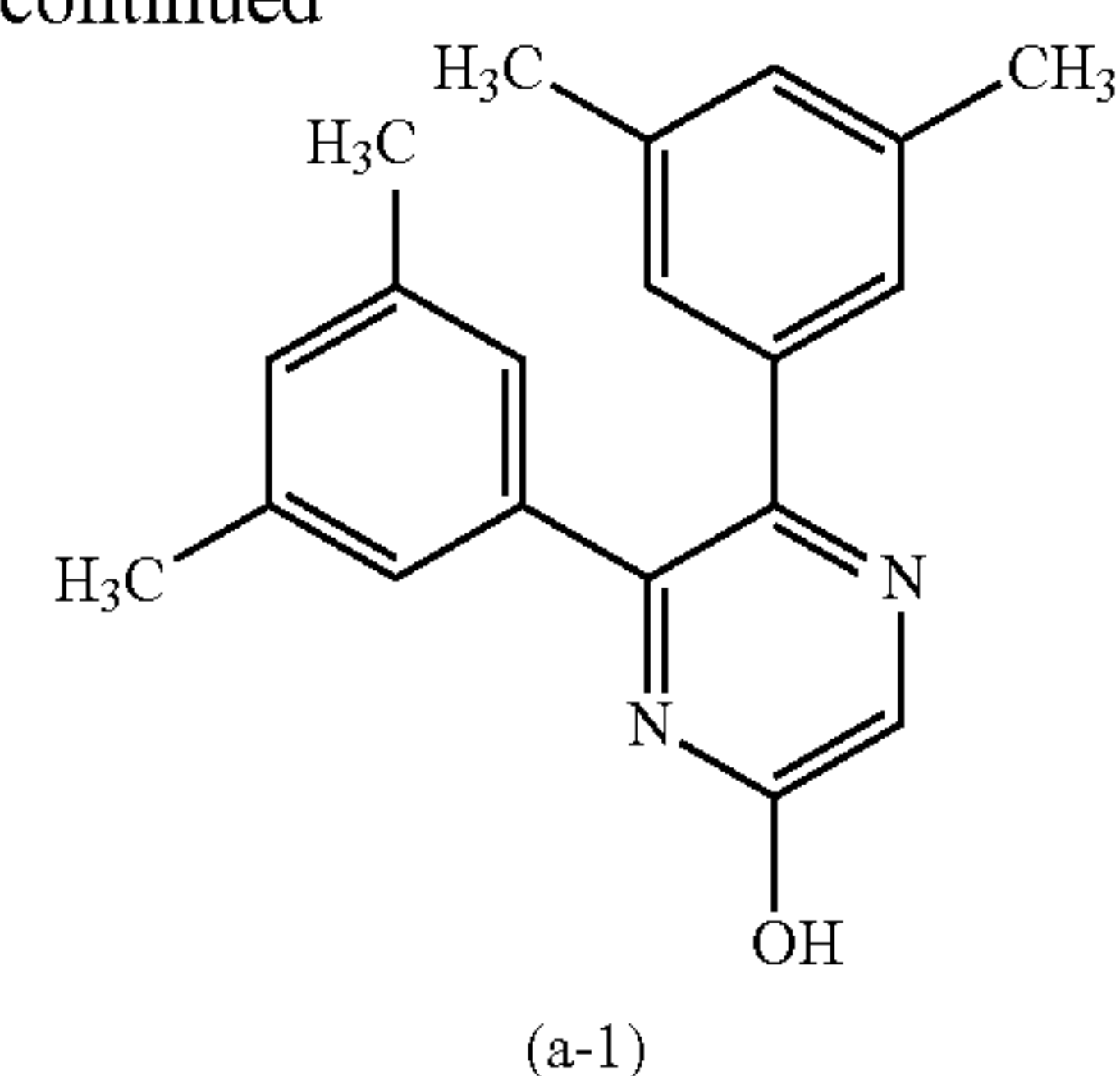
SYNTHESIS EXAMPLE 2

Step 1: Synthesis of 5-hydroxy-2,3-bis(3,5-dimethylphenyl)pyrazine

First, 5.27 g of 3,3',5,5'-tetramethylbenzyl, 2.61 g of glycine hydrochloride, 1.92 g of sodium hydroxide, and 50 mL of methanol were put into a three-neck flask equipped with a reflux pipe, the air in the flask was replaced with nitrogen, and the mixture was stirred at 80° C. for 7 hours to cause a reaction. Then, 2.5 mL of 12M hydrochloric acid was added thereto and stirring for 30 minutes was performed. Then, 2.02 g of potassium bicarbonate was added thereto and stirring for 30 minutes was performed. The resulting suspension was subjected to suction filtration. The obtained solid was washed with water and methanol, so that a target pyrazine derivative was obtained (a milky white powder, yield: 79%). A synthesis scheme of Step 1 is shown in (a-1).



-continued

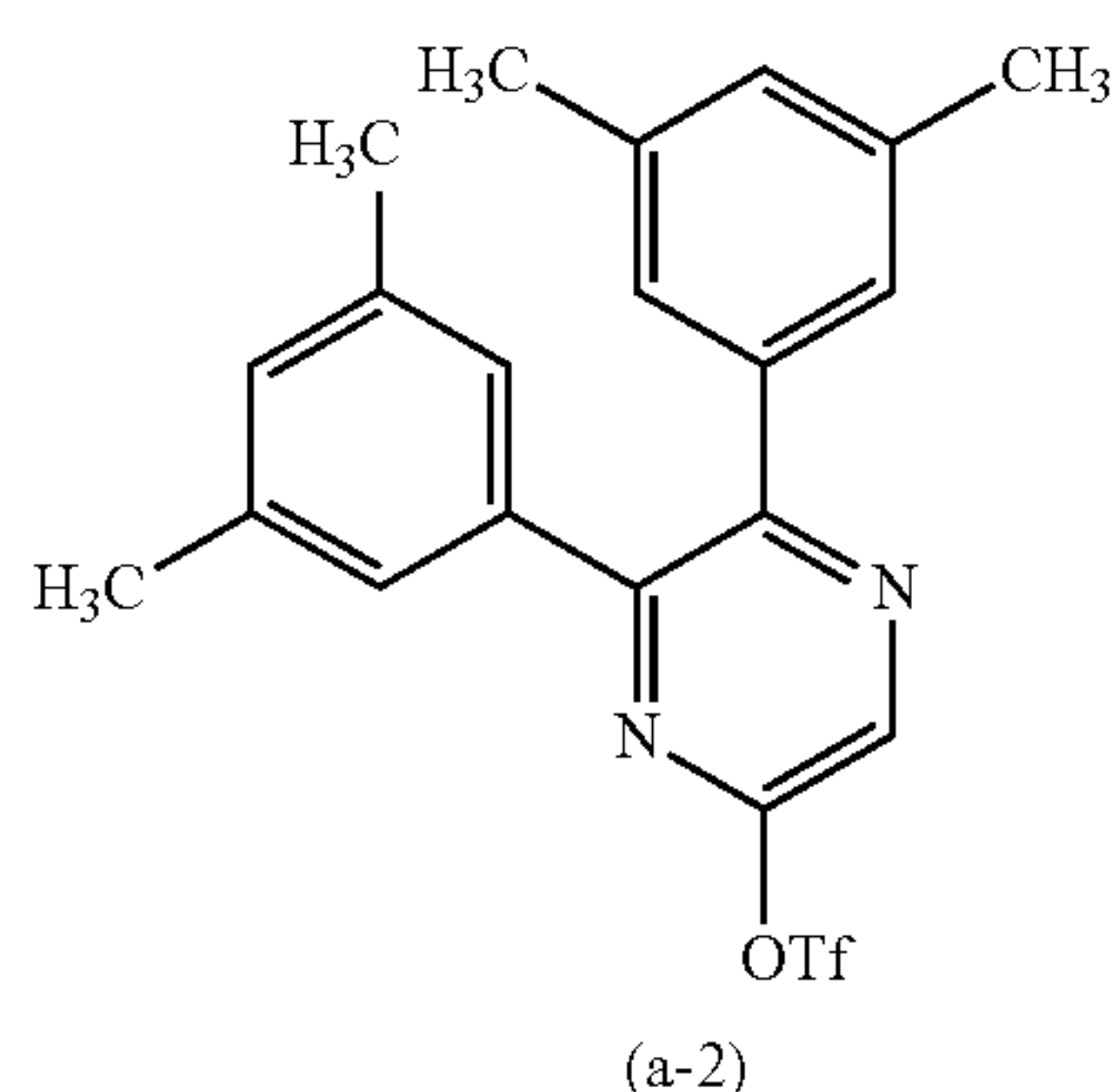
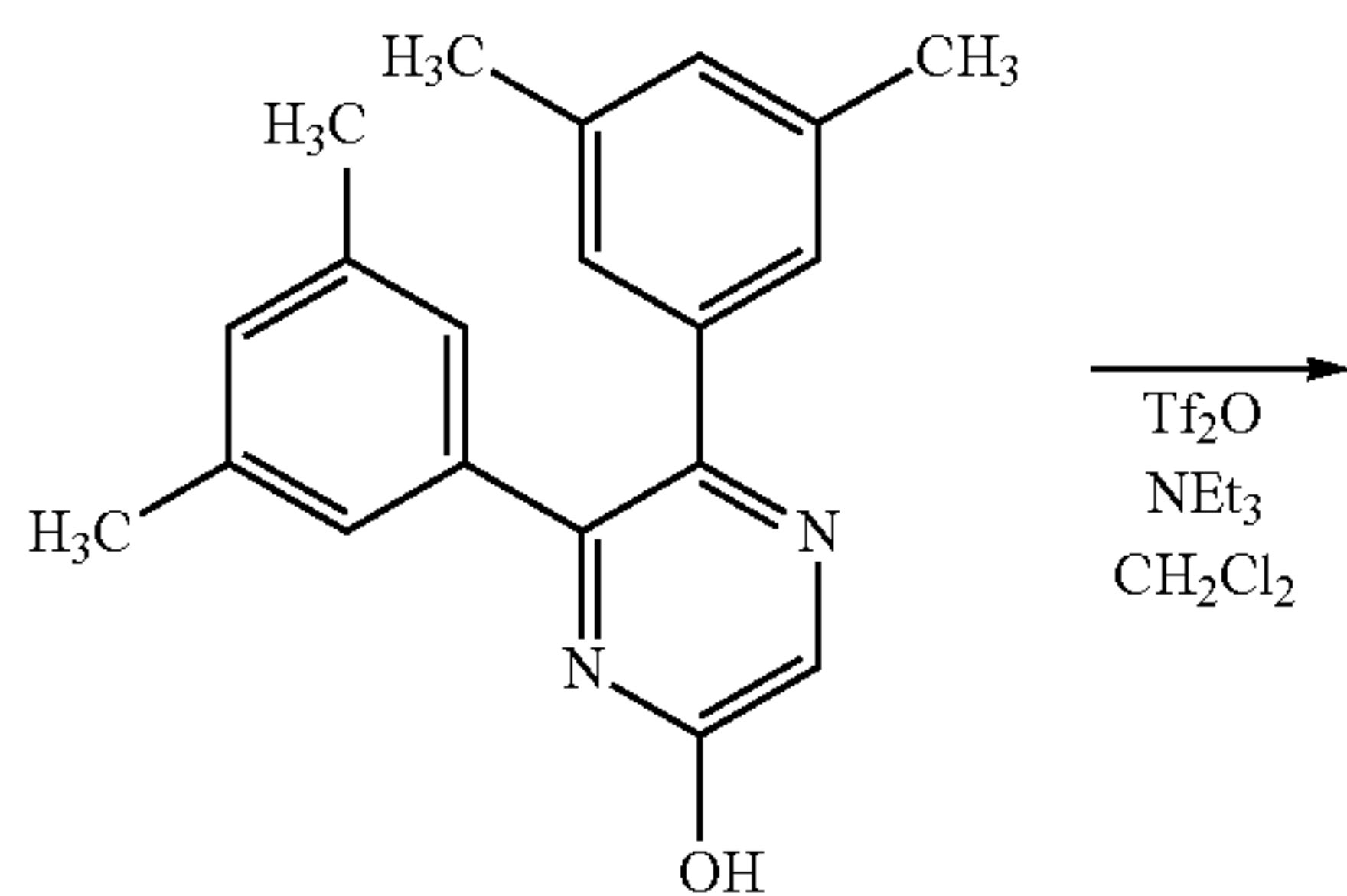


Step 2: Synthesis of
5,6-bis(3,5-dimethylphenyl)pyrazin-2-yl
trifluoromethanesulfonate

Next, 4.80 g of the 5-hydroxy-2,3-bis(3,5-dimethylphenyl)pyrazine which was obtained in Step 1, 4.5 mL of triethylamine, and 80 mL of dehydrated dichloromethane were put into a three-neck flask, and the air in the flask was replaced with nitrogen. The flask was cooled down to -20°C ., 3.5 mL of trifluoromethanesulfonic anhydride was dropped therein, and stirring at room temperature was performed for 17.5 hours. The flask was cooled down to 0°C ., 0.7 mL of trifluoromethanesulfonic anhydride was dropped therein, and stirring at room temperature was performed for 22 hours. Next, 50 mL of water and 5 mL of 1M hydrochloric acid were added to the reaction solution, and then dichloromethane was added to the reaction solution, so that a substance contained in the reaction solution was extracted in the dichloromethane. The solution of the extract was washed with a saturated aqueous solution of sodium hydrogen carbonate, and saturated saline. Then, magnesium sulfate was added thereto for drying. After being dried, the solution was filtered, and the filtrate was concentrated and the obtained residue was purified by silica gel column chromatography using toluene:hexane=1:1 (volume ratio) as a developing solvent, so that a target pyrazine derivative was obtained (yellow oil, yield: 96%). A synthesis scheme of Step 2 is shown in (a-2).

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[Chemical Formulae 11]

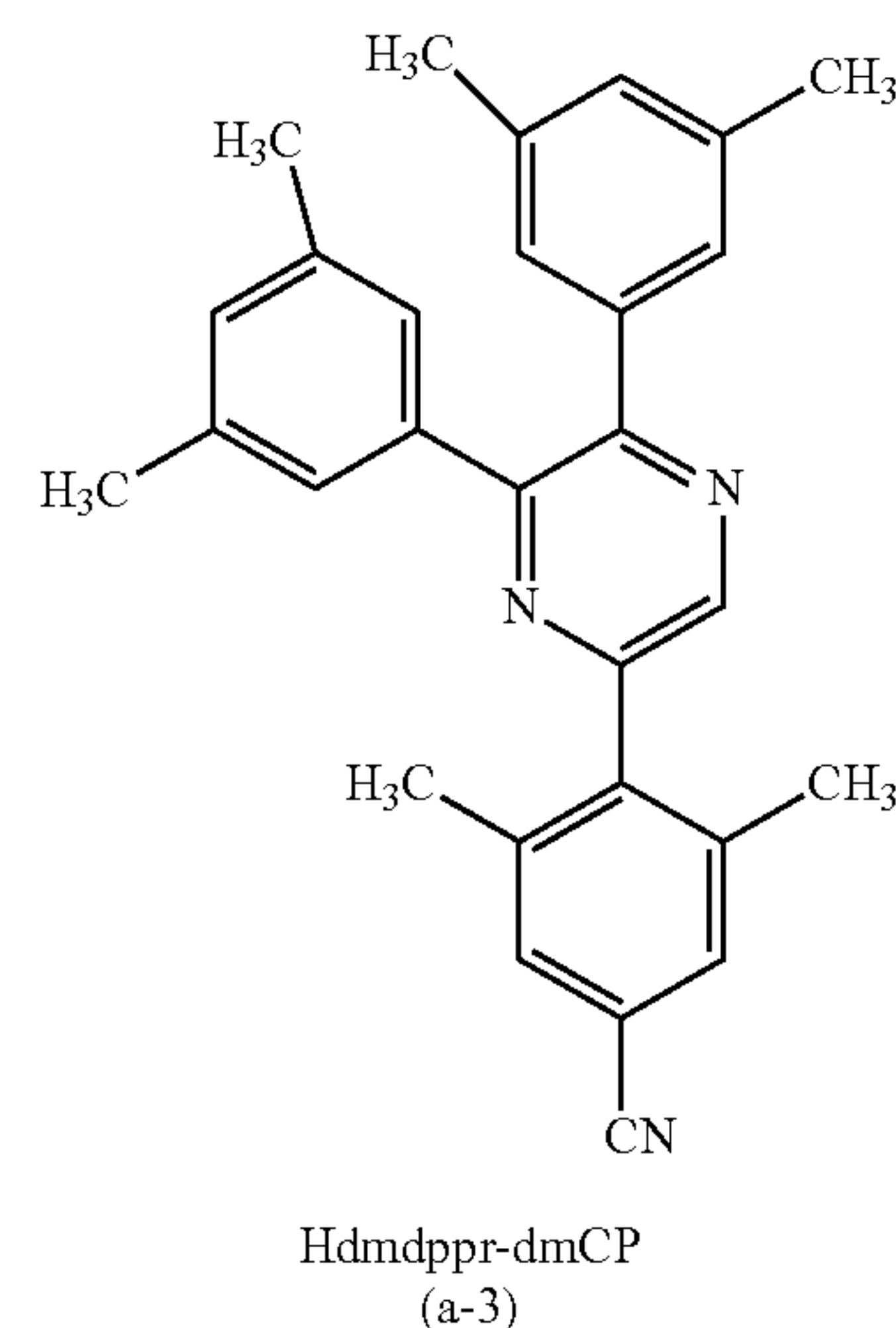
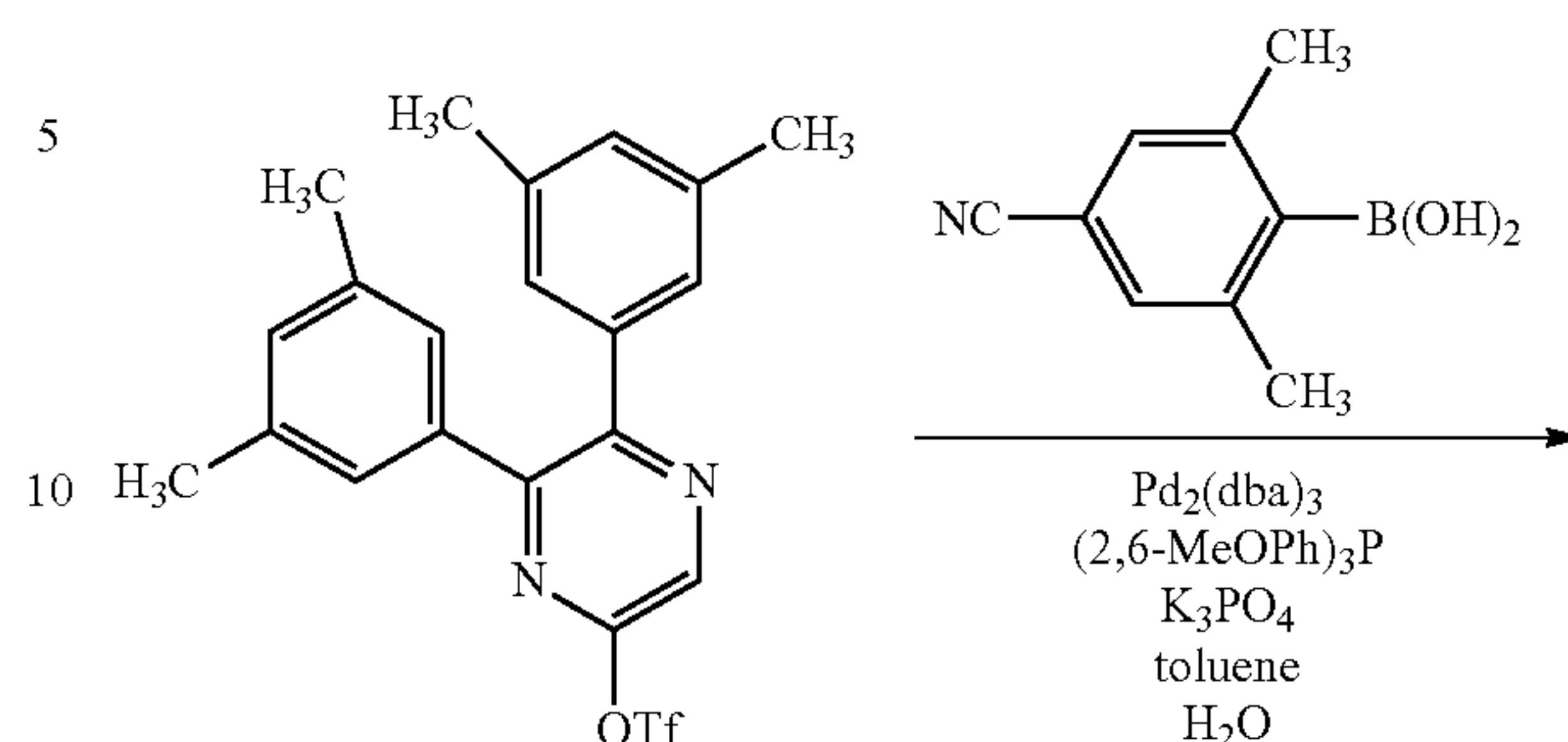


Step 3: Synthesis of 5-(4-cyano-2,6-dimethylphenyl)-2,3-bis(3,5-dimethylphenyl)pyrazine (abbreviation: Hdmdppr-dmCP)

Next, 2.05 g of 5,6-bis(3,5-dimethylphenyl)pyrazin-2-yl trifluoromethanesulfonate that was obtained in Step 2, 1.00 g of 4-cyano-2,6-dimethylphenylboronic acid, 3.81 g of tripotassium phosphate, 40 mL of toluene, and 4 mL of water are put into a three-neck flask, and the air in the flask was replaced with nitrogen. The mixture in the flask was degassed by being stirred under reduced pressure, 0.044 g of tris(dibenzylideneacetone)dipalladium(0) and 0.084 g of tris(2,6-dimethoxyphenyl)phosphine were added thereto and the mixture was refluxed for seven hours for reaction. Water was added to the reaction solution, and then toluene was added to the reaction solution, so that the substance contained in the reaction solution was extracted in the toluene. Saturated saline was added to the toluene solution, and the toluene solution was washed. Then, magnesium sulfate was added for drying. After being dried, the solution was filtered, and the filtrate was concentrated and the obtained residue was purified by silica gel column chromatography using hexane:ethyl acetate=5:1 (volume ratio) as a developing solvent, so that a target pyrazine derivative Hdmdppr-dmCP was obtained (white powder, yield: 90%). A synthesis scheme of Step 3 is shown in (a-3).

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[Chemical Formulae 12]



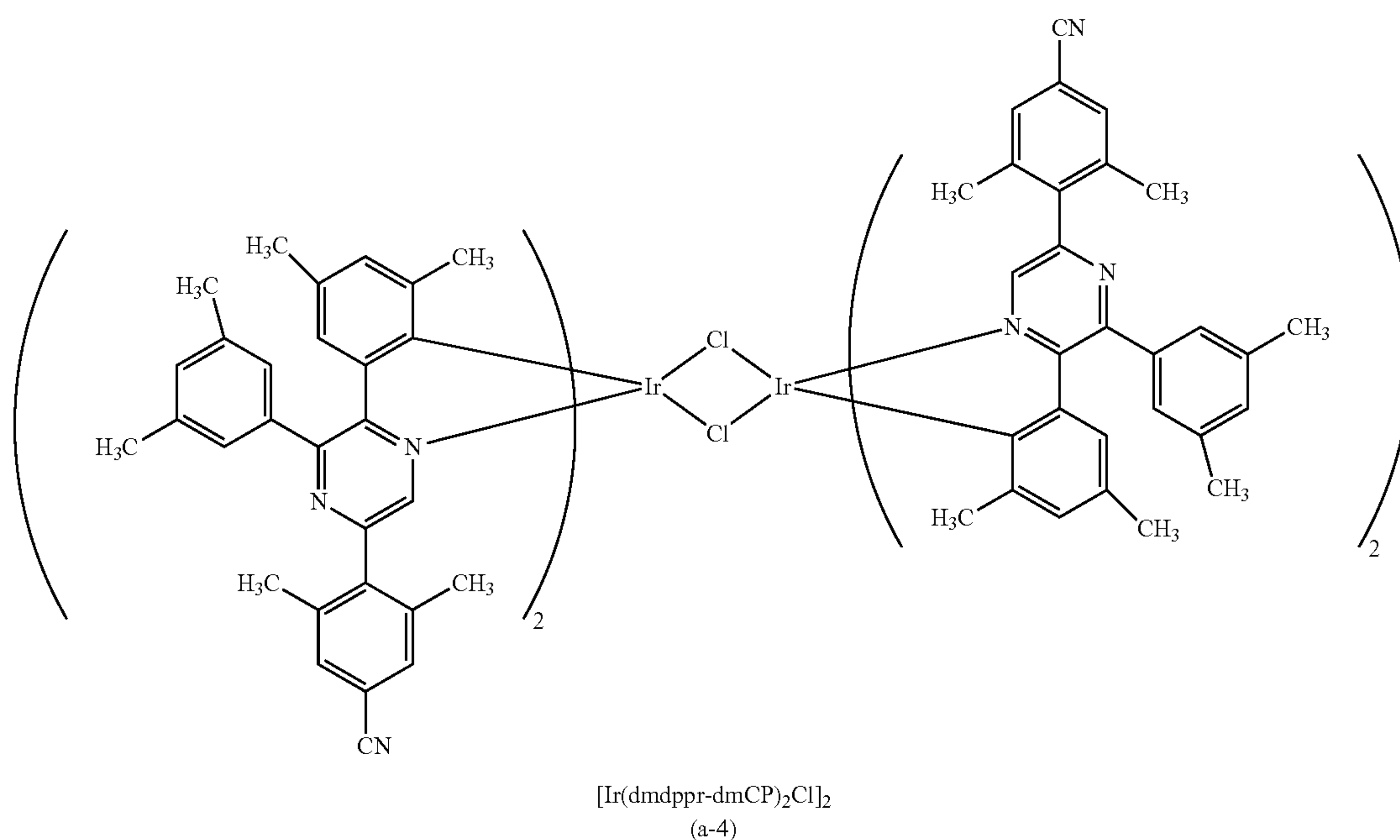
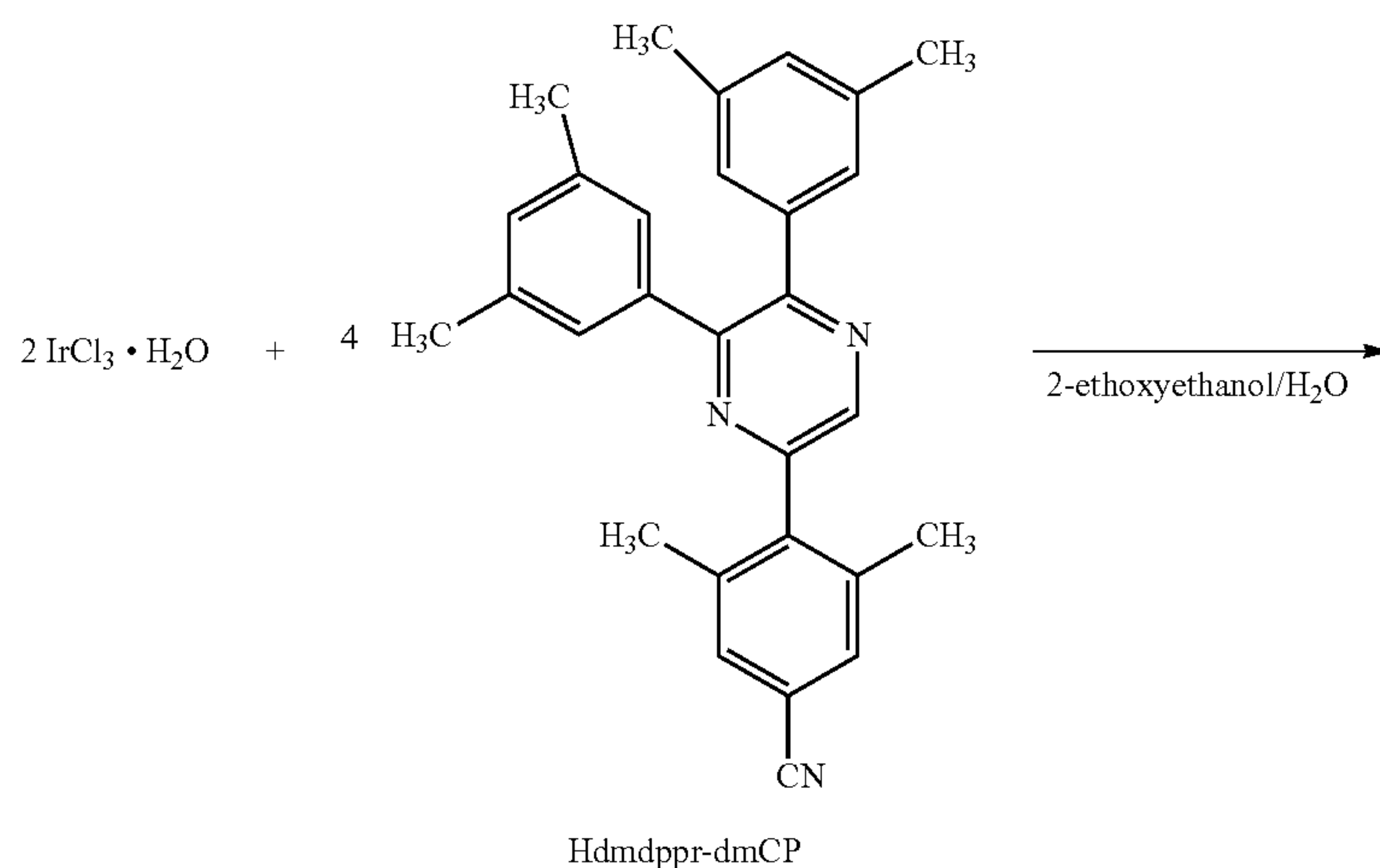
Step 4: Synthesis of di-μ-chloro-tetrakis{4,6-dimethyl-2-[5-(4-cyano-2,6-dimethylphenyl)-3-(3,5-dimethylphenyl)-2-pyrazinyl-κN]phenyl-κC}diiridium(III) (abbreviation: [Ir(dmdppr-dmCP)₂Cl]₂)

Next, 1.74 g of Hdmdppr-dmCP obtained in Step 3, 15 mL of 2-ethoxyethanol, 5 mL of water, and 0.60 g of iridium chloride hydrate (IrCl₃·xH₂O) (produced by Furuya Metal Co., Ltd.), were put into a recovery flask equipped with a reflux pipe, and the air in the flask was replaced with argon. After that, irradiation with microwaves (2.45 GHz, 100 W) was performed for 1 hour to cause a reaction. After the reaction, the solvent was distilled off, and the obtained residue was suction-filtered with hexane. The obtained solid was washed with methanol to give [Ir(dmdppr-dmCP)₂Cl]₂, which is a dinuclear complex, as a reddish brown powder in a yield of 89%. Synthesis Scheme (a-4) of Step 4 is shown below.

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[Chemical Formulae 13]



Step 5: Synthesis of bis{4,6-dimethyl-2-[5-(4-cyano-2,6-dimethylphenyl)-3-(3,5-dimethylphenyl)-2-pyrazinyl-κN]phenyl-κC}(2,2',6,6'-tetramethyl-3,5-heptanedionate-κ²O,O')iridium(III) (abbreviation: $[\text{Ir}(\text{dmdppr-dmCP})_2(\text{dpm})]$)

Furthermore, in a recovery flask equipped with a reflux pipe were put 30 mL of 2-ethoxyethanol, 0.96 g of $[\text{Ir}(\text{dmdppr-dmCP})_2\text{Cl}]_2$ that is the dinuclear complex obtained in Step 4, 0.26 g of dipivaloylmethane (abbreviation: Hdpm), and 0.48 g of sodium carbonate, and the air in the flask was replaced with argon. Then, irradiation with micro-
waves (2.45 GHz, 100 W) was performed for 60 minutes. Moreover, 0.13 g of Hdpm was added thereto, and the reaction container was subjected to microwave irradiation
for 60 minutes to cause a reaction. After the reaction, the solvent of this solution was distilled off, and

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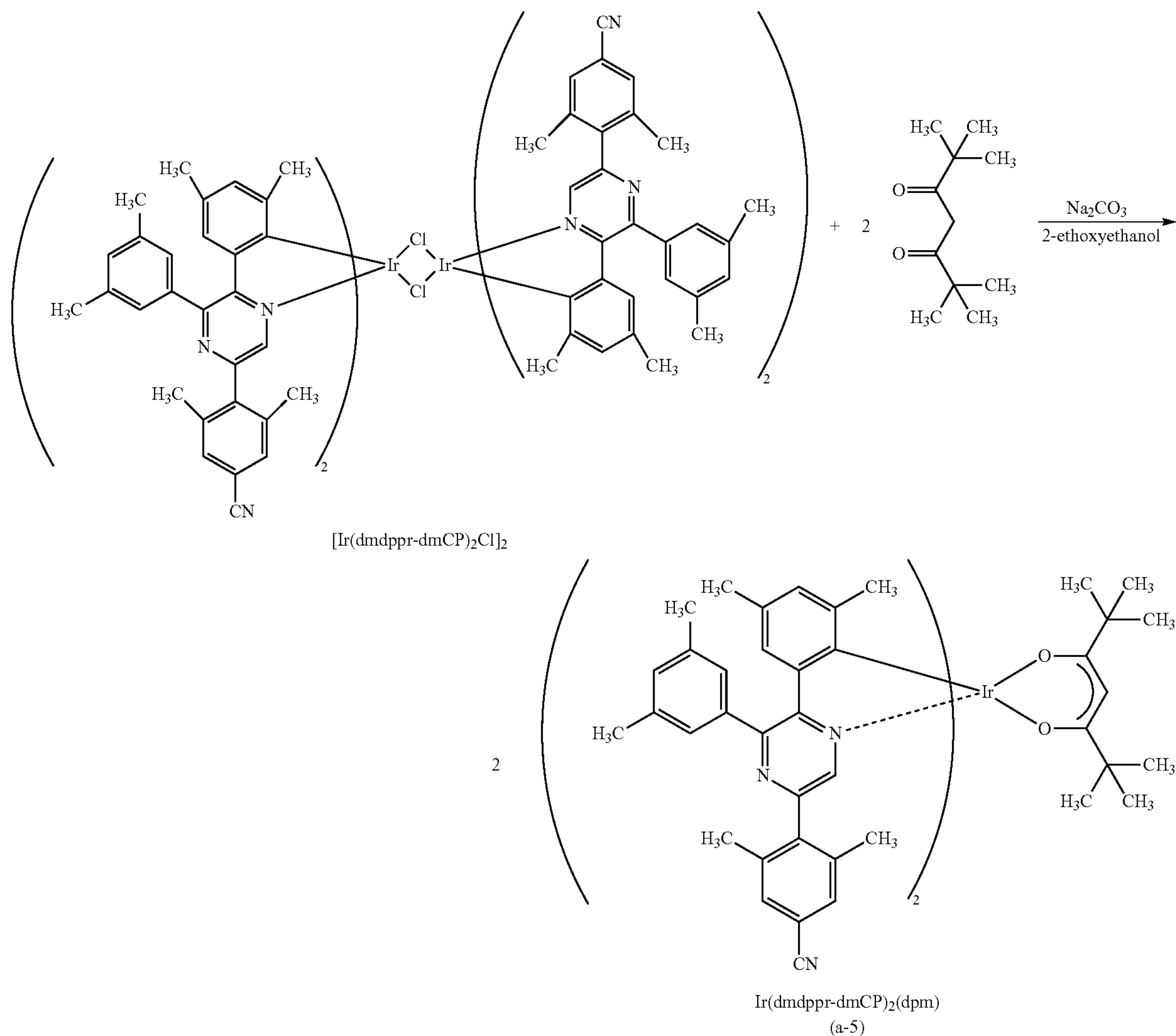
65

then the obtained residue was purified by silica gel column chromatography using dichloromethane and hexane as a developing solvent in a volume ratio of 1:1. This solid was purified by silica gel column chromatography using dichloromethane as a developing solvent and recrystallized with a mixed solvent of dichloromethane and hexane to give red powder of $\text{Ir}(\text{dmdppr-dmCP})_2(\text{dpm})$ (yield of 37%). By a train sublimation method, 0.39 g of the obtained red powdered solid, which was the objective substance, was purified. In the purification, the red powdered solid was heated at 300° C. under a pressure of 2.6 Pa with a flow rate of argon gas of 5 mL/min. After the purification by sublimation, a red solid, which was a target substance, was obtained in a yield of 85%. A synthetic scheme of Step 5 is shown in (a-5) below.

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[Chemical Formulae 14]



Note that results of the analysis in which the red powders obtained in the above Step 5 were analyzed by nuclear magnetic resonance spectrometry ($^1\text{H-NMR}$) are given below.

$^1\text{H-NMR}$. δ (CD_2Cl_2): 0.91 (s, 18H), 1.41 (s, 6H), 1.95 (s, 6H), 2.12 (s, 12H), 2.35 (s, 12H), 5.63 (s, 1H), 6.49 (s, 2H), 6.86 (s, 2H), 7.17 (s, 2H), 7.34 (s, 4H), 7.43 (s, 4H), 8.15 (s, 2H).

EXPLANATION OF REFERENCE

100: EL layer, **101**: electrode, **101a**: conductive layer, **101b**: conductive layer, **101c**: conductive layer, **102**: electrode, **103**: electrode, **103a**: conductive layer, **103b**: conductive layer, **104**: electrode, **104a**: conductive layer, **104b**: conductive layer, **106**: light-emitting unit, **108**: light-emitting unit, **110**: EL layer, **111**: hole-injection layer, **112**: hole-transport layer, **113**: electron-transport layer, **114**: electron-injection layer, **115**: charge-generation layer, **116**: hole-injection layer, **117**: hole-transport layer, **118**: electron-transport layer, **118(1)**: layer, **118(2)**: layer, **119**: electron-injection layer,

120: light-emitting layer, **121**: host material, **122**: guest material, **123B**: light-emitting layer, **123G**: light-emitting layer, **123R**: light-emitting layer, **140**: light-emitting layer, **141**: host material, **141_1**: organic compound, **141_2**: organic compound, **142**: guest material, **145**: partition wall, **152**: light-emitting element, **160**: light-emitting layer, **160(1)**: layer, **160(2)**: layer, **170**: light-emitting layer, **171**: host material, **171_1**: organic compound, **171_2**: organic compound, **172**: guest material, **180**: light-emitting layer, **190**: light-emitting layer, **190a**: light-emitting layer, **190b**: light-emitting layer, **200**: substrate, **220**: substrate, **221B**: region, **221G**: region, **221R**: region, **222B**: region, **222G**: region, **222R**: region, **223**: light-blocking layer, **224B**: optical element, **224G**: optical element, **224R**: optical element, **250**: light-emitting element, **252**: light-emitting element, **260a**: light-emitting element, **260b**: light-emitting element, **262a**: light-emitting element, **262b**: light-emitting element, **301_1**: wiring, **301_5**: wiring, **301_6**: wiring, **301_7**: wiring, **302_1**: wiring, **302_2**: wiring, **303_1**: transistor, **303_6**: transistor, **303_7**: transistor, **304**: capacitor, **304_1**: capacitor, **304_2**:

capacitor, 305: light-emitting element, 306_1: wiring, 306_3: wiring, 307_1: wiring, 307_3: wiring, 308_1: transistor, 308_6: transistor, 309_1: transistor, 309_2: transistor, 311_1: wiring, 311_3: wiring, 312_1: wiring, 312_2: wiring, 600: display device, 601: signal line driver circuit portion, 602: pixel portion, 603: scan line driver circuit portion, 604: sealing substrate, 605: sealant, 607: region, 607a: sealing layer, 607b: sealing layer, 607c: sealing layer, 608: wiring, 609: FPC, 610: element substrate, 611: transistor, 612: transistor, 613: lower electrode, 614: partition wall, 616: EL layer, 617: upper electrode, 618: light-emitting element, 621: optical element, 622: light-blocking layer, 623: transistor, 624: transistor, 801: pixel circuit, 802: pixel portion, 804: driver circuit portion, 804a: scan line driver circuit, 804b: signal line driver circuit, 806: protection circuit, 807: terminal portion, 852: transistor, 854: transistor, 862: capacitor, 872: light-emitting element, 1001: substrate, 1002: base insulating film, 1003: gate insulating film, 1006: gate electrode, 1007: gate electrode, 1008: gate electrode, 1020: interlayer insulating film, 1021: interlayer insulating film, 1022: electrode, 1024B: lower electrode, 1024G: lower electrode, 1024R: lower electrode, 1024Y: lower electrode, 1025: partition wall, 1026: upper electrode, 1028: EL layer, 1028B: light-emitting layer, 1028G: light-emitting layer, 1028R: light-emitting layer, 1028Y: light-emitting layer, 1029: sealing layer, 1031: sealing substrate, 1032: sealant, 1033: base material, 1034B: coloring layer, 1034G: coloring layer, 1034R: coloring layer, 1034Y: coloring layer, 1035: light-blocking layer, 1036: overcoat layer, 1037: interlayer insulating film, 1040: pixel portion, 1041: driver circuit portion, 1042: peripheral portion, 2000: touch panel, 2001: touch panel, 2501: display device, 2502R: pixel, 2502t: transistor, 2503c: capacitor, 2503g: scan line driver circuit, 2503s: signal line driver circuit, 2503t: transistor, 2509: FPC, 2510: substrate, 2510a: insulating layer, 2510b: flexible substrate, 2510c: adhesive layer, 2511: wiring, 2519: terminal, 2521: insulating layer, 2528: partition, 2550R: light-emitting element, 2560: sealing layer, 2567BM: light-blocking layer, 2567p: anti-reflective layer, 2567R: coloring layer, 2570: substrate, 2570a: insulating layer, 2570b: flexible substrate, 2570c: adhesive layer, 2580R: light-emitting module, 2590: substrate, 2591: electrode, 2592: electrode, 2593: insulating layer, 2594: wiring, 2595: touch sensor, 2597: adhesive layer, 2598: wiring, 2599: connection layer, 2601: pulse voltage output circuit, 2602: current sensing circuit, 2603: capacitor, 2611: transistor, 2612: transistor, 2613: transistor, 2621: electrode, 2622: electrode, 3000: light-emitting device, 3001: substrate, 3003: substrate, 3005: light-emitting element, 3007: sealing region, 3009: sealing region, 3011: region, 3013: region, 3014: region, 3015: substrate, 3016: substrate, 3018: desiccant, 3500: multifunction terminal, 3502: housing, 3504: display portion, 3506: camera, 3508: lighting, 3600: light, 3602: housing, 3608: lighting, 3610: speaker, 8000: display module, 8001: upper cover, 8002: lower cover, 8003: FPC, 8004: touch sensor, 8005: FPC, 8006: display device, 8009: frame, 8010: printed wiring board, 8011: battery, 8501: lighting device, 8502: lighting device, 8503: lighting device, 8504: lighting device, 9000: housing, 9001: display portion, 9003: speaker, 9005: operation key, 9006: connection terminal, 9007: sensor, 9008: microphone, 9050: operation button, 9051: information,

9052: information, 9053: information, 9054: information, 9055: hinge, 9100: portable information terminal, 9101: portable information terminal, 9102: portable information terminal, 9200: portable information terminal, 9201: portable information terminal, 9300: television set, 9301: stand, 9311: remote controller, 9500: display device, 9501: display panel, 9502: display region, 9503: region, 9511: hinge, 9512: bearing, 9700: automobile, 9701: car body, 9702: wheels, 9703: dashboard, 9704: light, 9710: display portion, 9711: display portion, 9712: display portion, 9713: display portion, 9714: display portion, 9715: display portion, 9721: display portion, 9722: display portion, and 9723: display portion.

This application is based on Japanese Patent Application serial No. 2015-144265 filed with Japan Patent Office on Jul. 21, 2015, the entire contents of which are hereby incorporated by reference.

The invention claimed is:

1. A light-emitting element comprising:

a first electrode;

a light emitting layer over the first electrode; and

a second electrode over the light emitting layer,

wherein the light emitting layer comprises:

a first organic compound;

a second organic compound; and

a guest material,

wherein a LUMO level of the first organic compound is lower than a LUMO level of the second organic compound,

wherein a HOMO level of the first organic compound is lower than a HOMO level of the second organic compound,

wherein a LUMO level of the guest material is lower than the LUMO level of the first organic compound,

wherein an energy difference between the LUMO level of the guest material and a HOMO level of the guest material is larger than an energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound,

wherein the energy difference between the LUMO level of the guest material and the HOMO level of the guest material is larger than transition energy calculated from an absorption edge of an absorption spectrum of the guest material by 0.5 eV or more,

wherein the guest material is configured to convert triplet excitation energy into light emission, and

wherein combination of the first organic compound and the second organic compound is configured to form an exciplex.

2. The light-emitting element according to claim 1, wherein the energy difference between the LUMO level of the guest material and the HOMO level of the guest material is larger than a light emission energy of the guest material by 0.4 eV or more.

3. The light-emitting element according to claim 1, wherein the exciplex is configured to transfer excitation energy to the guest material.

4. The light-emitting element according to claim 1, wherein an emission spectrum of the exciplex has a region overlapping with an absorption band on the longest wavelength side of an absorption spectrum of the guest material.

5. The light-emitting element according to claim 1, wherein the guest material comprises iridium.

6. The light-emitting element according to claim 1, wherein the first organic compound is configured to transport an electron, and

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wherein the second organic compound is configured to transport a hole.

7. The light-emitting element according to claim 1, wherein the first organic compound comprises a π -electron deficient heteroaromatic ring skeleton, and wherein the second organic compound comprises at least one of a π -electron rich heteroaromatic ring skeleton and an aromatic amine skeleton.

8. A display device comprising:
the light-emitting element according to claim 1; and
at least one of a color filter, a sealant, and a transistor.

9. An electronic device comprising:
the display device according to claim 8; and
at least one of a housing and a touch sensor.

10. A lighting device comprising:
the light-emitting element according to claim 1; and
at least one of a housing and a touch sensor.

11. A light-emitting element comprising:
a first electrode;
a light emitting layer over the first electrode; and
a second electrode over the light emitting layer,
wherein the light emitting layer comprises:
a first organic compound;
a second organic compound; and
a guest material,
wherein a LUMO level of the first organic compound is lower than a LUMO level of the second organic compound,
wherein a HOMO level of the first organic compound is lower than a HOMO level of the second organic compound,
wherein a LUMO level of the guest material is lower than the LUMO level of the first organic compound,
wherein an energy difference between the LUMO level of the guest material and a HOMO level of the guest material is larger than an energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound,
wherein the energy difference between the LUMO level of the guest material and the HOMO level of the guest material is larger than the transition energy calculated from the absorption edge of the absorption spectrum of the guest material by 0.5 eV or more,
wherein the guest material is configured to convert triplet excitation energy into light emission,
wherein combination of the first organic compound and the second organic compound is configured to form an exciplex, and
wherein an energy difference between the LUMO level of the guest material and the HOMO level of the second organic compound is larger than or equal to transition energy calculated from an absorption edge of an absorption spectrum of the guest material.

12. The light-emitting element according to claim 11, wherein the energy difference between the LUMO level of the guest material and the HOMO level of the guest material is larger than a light emission energy of the guest material by 0.4 eV or more.

13. The light-emitting element according to claim 11, wherein the exciplex is configured to transfer excitation energy to the guest material.

14. The light-emitting element according to claim 11, wherein an emission spectrum of the exciplex has a region overlapping with an absorption band on the longest wavelength side of the absorption spectrum of the guest material.

15. The light-emitting element according to claim 11, wherein the guest material comprises iridium.

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16. The light-emitting element according to claim 11, wherein the first organic compound is configured to transport an electron, and wherein the second organic compound is configured to transport a hole.

17. The light-emitting element according to claim 11, wherein the first organic compound comprises a π -electron deficient heteroaromatic ring skeleton, and wherein the second organic compound comprises at least one of a π -electron rich heteroaromatic ring skeleton and an aromatic amine skeleton.

18. A display device comprising:
the light-emitting element according to claim 11; and
at least one of a color filter, a sealant, and a transistor.

19. An electronic device comprising:
the display device according to claim 18; and
at least one of a housing and a touch sensor.

20. A lighting device comprising:
the light-emitting element according to claim 11; and
at least one of a housing and a touch sensor.

21. A light-emitting element comprising:
a first electrode;
a light emitting layer over the first electrode; and
a second electrode over the light emitting layer,
wherein the light emitting layer comprises:
a first organic compound;
a second organic compound; and
a guest material,
wherein a LUMO level of the first organic compound is lower than a LUMO level of the second organic compound,
wherein a HOMO level of the first organic compound is lower than a HOMO level of the second organic compound,
wherein a LUMO level of the guest material is lower than the LUMO level of the first organic compound,
wherein an energy difference between the LUMO level of the guest material and a HOMO level of the guest material is larger than an energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound,
wherein the energy difference between the LUMO level of the guest material and the HOMO level of the guest material is larger than the transition energy calculated from the absorption edge of the absorption spectrum of the guest material by 0.5 eV or more,
wherein the guest material is configured to convert triplet excitation energy into light emission,
wherein combination of the first organic compound and the second organic compound is configured to form an exciplex, and
wherein an energy difference between the LUMO level of the guest material and the HOMO level of the second organic compound is larger than or equal to light emission energy of the guest material.

22. The light-emitting element according to claim 21, wherein the energy difference between the LUMO level of the guest material and the HOMO level of the guest material is larger than the light emission energy of the guest material by 0.4 eV or more.

23. The light-emitting element according to claim 21, wherein the exciplex is configured to transfer excitation energy to the guest material.

24. The light-emitting element according to claim 21, wherein an emission spectrum of the exciplex has a region overlapping with an absorption band on the longest wavelength side of an absorption spectrum of the guest material.

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25. The light-emitting element according to claim 21, wherein the guest material comprises iridium.

26. The light-emitting element according to claim 21, wherein the first organic compound is configured to transport an electron, and wherein the second organic compound is configured to transport a hole.

27. The light-emitting element according to claim 21, wherein the first organic compound comprises a π -electron deficient heteroaromatic ring skeleton, and wherein the second organic compound comprises at least one of a π -electron rich heteroaromatic ring skeleton and an aromatic amine skeleton.

28. A display device comprising: the light-emitting element according to claim 21; and at least one of a color filter, a sealant, and a transistor.

29. An electronic device comprising: the display device according to claim 28; and at least one of a housing and a touch sensor.

30. A lighting device comprising: the light-emitting element according to claim 21; and at least one of a housing and a touch sensor.

31. The light-emitting element according to claim 2, wherein the light emission energy of the guest material is smaller than or equal to the transition energy calculated from the absorption spectrum edge of the guest material.

32. The light-emitting element according to claim 12, wherein the light emission energy of the guest material is smaller than or equal to the transition energy calculated from the absorption spectrum edge of the guest material.

33. The light-emitting element according to claim 1, wherein the HOMO level of the guest material is lower than the HOMO level of the second organic compound.

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34. The light-emitting element according to claim 11, wherein the HOMO level of the guest material is lower than the HOMO level of the second organic compound.

35. The light-emitting element according to claim 1, wherein transition energy calculated from an absorption edge of an absorption spectrum of the guest material is smaller than or equal to the energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound.

36. The light-emitting element according to claim 11, wherein the transition energy calculated from the absorption edge of the absorption spectrum of the guest material is smaller than or equal to the energy difference between the LUMO level of the first organic compound and the HOMO level of the second organic compound.

37. The light-emitting element according to claim 1, wherein the second organic compound comprises one of PCBBiF, PCzPCFL, and PCBiF.

38. The light-emitting element according to claim 11, wherein the second organic compound comprises one of PCBBiF, PCzPCFL, and PCBiF.

39. The light-emitting element according to claim 1, wherein a difference between of the LUMO level of the first organic compound and the LUMO level of the guest material is larger than 0 eV and smaller than or equal to 0.15 eV.

40. The light-emitting element according to claim 11, wherein a difference between of the LUMO level of the first organic compound and the LUMO level of the guest material is larger than 0 eV and smaller than or equal to 0.15 eV.

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